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DETERMINATION OF OPTIMUM TROPIC STORAGE AND EXPOSURE SITES. REPORT I: SURVEY OF PROGRAMS IN TROPIC MATERIALS RESEARCH

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DETERMINATION OF OPTIMUM TROPIC STORAGE AND EXPOSURE SITES

REPORT I:

SURVEY OF PROGRAMS IN TROPIC MATERIALS RESEARCH

By

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April 1973

UNITED STATES ARMY TROPIC TEST CENTER

APO NEW YORK 09827

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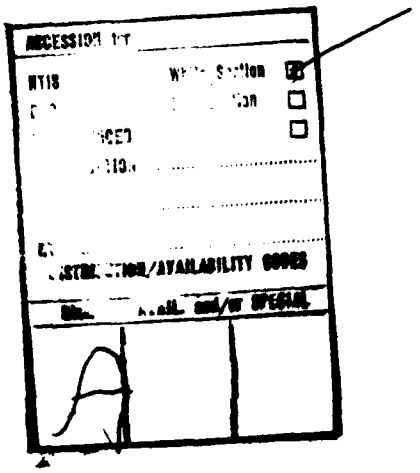

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The US Army Tropic Test Center initiated a project in February 1971 entitled, "Determination of Optimum Tropic Storage and Exposure Sites." The objectives of this investigation were to (a) determine the relative severity of environmental effects at experimental and established exposure sites and assign severity rates, (b) determine deterioration rates and patterns of six basic materials, (c) develop techniques for detecting early onset of deterioration, (d) survey the existing literature that pertains to the deterioration of materials exposed in the tropics; (e) determine the effects of tropic wet and dry seasons on deterioration; and (f) use the results to develop or update applicable storage and exposure Test Operation Procedures.

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The main criterion for selecting the articles reviewed was relevancy to the Optimum Sites project. Selections were limited to articles dealing with the establishment of international tropic exposure sites and deterioration articles concerning materials commonly used in US Army equipment. Selected literature consisted of journal articles, papers, and books on the tropic deterioration of plastics, rubber, steel, and textiles.

The survey presents a historical development of tropic exposure sites and tropic deteriorative investigations. Conclusions are drawn on the relative deteriorative effects of climatic and biological factors.

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TABLE OF CONTENTS

SECTION A. INTERNATIONAL PROGRAMS IN TROPIC MATERIALS RESEARCH

1. INTRODUCTION

In the Pacific Theater, during World War II, the problem of tropical deterioration became acute. Large scale activities in tropic areas magnified a little known problem of material degradation. The problem became very serious when equipment loss hampered combat operations, and the need for development of methods and locations to study the degradative effects of a tropic environment became apparent. The establishment of tropic exposure sites allowed investigations to be conducted in a scientific manner as to causes and results of, and countermeasures against, material deterioration.

2. OBJECTIVE

The objective of this literature survey is to present a historical development of tropic exposure sites and tropic deterioration studies associated with four selected materials. The presentation, in historical order, consists of major international papers since World War II that deal with the causes and results of material research in tropic deterioration. This report is not intended as an all-inclusive literature survey, but deals only with major international accomplishments in materials research used for planning TECOM Project No. 9 CO 009 000 006, *Determination of Optimum Tropic Storage and Exposure Sites.*

3. DETAILS OF INVESTIGATION

This investigation was initiated through a survey of available literature dealing with tropic exposure. Areas of consideration were exposure sites, plastics, rubbers, metals and textiles, as they concern deterioration in the tropics. The details of investigation of these five areas appear below in historical order:

a. Tropic Exposure Sites

In 1944, a conference was attended by selected Army and Navy officers and Office of Scientific Research and Development representatives to determine the various interests in tropic exposure problems, and to consider founding an organization to coordinate subsequent investigations on deterioration of materials and equipment. Three committees were formed, the Joint Army-Navy National Defense Research Committee (NDRC), Tropical Deterioration Steering Committee (TDSC) and the Tropical Deterioration Administrative Committee (TDAC). Subsequently, the Tropical Deterioration Information Center was established as a central repository for all available reports, foreign and domestic. Abstracts of articles were published in a semimonthly bulletin[16]. Many of the tests conducted by the TDAC were conducted in whole or in part at the Panama Test Station, located in the Canal Zone on Barro Colorado Island in Gatun Lake[80, 81].

In 1945, the Australian Scientific Liaison Bureau[101] called a conference of the Services and the Relevant Commonwealth Departments to consider the general problems involved in the tropics. As a result, a scientific mission was sent to tropic operational

areas. The Bureau inaugurated a Tropical Scientific Section which examined materials in the field and conducted field test of materials and procedures formulated by the Inter-Service Committees.

In 1945, the Indian Government[20] issued a list of microorganisms which caused damage in India to ordnance stores. It noted that species present on damaged stores varied with the season, location, type of store, history of storage, and length of exposure.

In 1945, the Comptroller General of Chemical Research and Development, British Ministry of Supply[27], extended invitations to the United States military services to send representatives[6] to British research establishments working on prevention of tropic deterioration of military materiel. The visit was planned to permit an inspection of facilities and an exchange of information and ideas among technical personnel. Experimental work in Great Britain followed closely with the work being done in the United States. Extended visits to the United States had been made by the British for the study of electronic equipment and packaging. New electronic equipment was being designed so that all units were hermetically sealed and mold-susceptible materials were eliminated. Old and new equipment were given an overall spray of fungicidal varnish. Differences in specifications and procedures between the two countries were largely due to differences in available materials and in supply functions. Most laboratory fungus testing in Great Britain was supplemented by parallel work at the West African Tropical Testing Establishment in Nigeria. Various types of jungle sites were available there, so that equipment could be operated under actual field conditions. The station corresponded very closely to that of the Artillery Tropical Testing Mission in the Canal Zone, although the latter carried out more extensive testing. To obtain the greatest benefit from a tropic test program, it was believed that all information pertaining to exposed materials should be made available and that competent personnel should follow the tests at the site and interpret the results. It was found that when materials and materiel were exposed and then returned to temperate zones for evaluation, much of the value of the study was lost because of lack of information regarding behavior during exposure and the possibility of unknown changes occurring after leaving the station. Although simulated tropic tests gave a quick check on the performance of materiel, concurrent tests at a tropic test station yielded results that were not always consistent with simulations.

In 1945, the United States Office of Technical Services published a synopsis[83] of the tropic protective measures practiced by the Japanese during World War II. Although the Japanese were aware of the problems of tropic deterioration of improperly protected materiel, neither fungicides nor radioactive materials were used to prevent fungus growth. Emphasis was placed on moisture proofing the material rather than incorporating fungicides. The wartime state of development in the protective coating field was gained through information published in trade magazines by employees formerly employed in the United States, and affiliation with United States corporations which supplied the results of their work. At the end of the war the Japanese were found to be 15 to 20 years behind the United States in their investigations in the protective coatings field. No information of technical value to the United States in the field of tropical protective coatings was obtained as a result of Japanese investigations. Neither was there any evidence that Japan received any technical assistance from Germany, Italy, or any source other than the United States. The most severe handicap to Japanese progress in this field was shortage of raw materials, thus development was limited largely to finding substiute materials.

In 1945, the TDAC issued a *Handbook of Some Fungi Associated with Tropical Deterioration*[80]. This document gave a good description of the morphology and physiology of fungi, and classification of fungi including illustrations.

As early as 1945 it was realized that Barro Colorado, an island in Panama formed as a result of the building of the Panama Canal, was not a typical tropical exposure site, and that other sites might be more representative. In that year the US Army Frankford Arsenal established a Tropical Testing Station at Fort Sherman, Canal Zone, for the purpose of testing ordnance materials and materiel. The environmental conditions at this station were described by Teitell in 1946[112]. Two sites were described, one now known as "Skunk Hollow," and a marine site on a peninsula jutting into Limon Bay. Since then a wide variety of materials and coatings have been exposed at the Skunk Hollow site which is still in use. The other site was subsequently moved to the Fort Sherman Breakwater because of the desirability of a more severe salt spray at the coastal site.

In 1946, at the first meeting of the Joint Army-Navy Deterioration Prevention Committee[65], it was agreed to form seven subcommittees in order to group similar interests. A brief history was given of the development of the Exposure Station at Barro Colorado Island, Canal Zone, and plans were mentioned for transferring the station to Fort Sherman, Canal Zone.

In 1946, the US Army Air Forces Tropical Science Mission[115] issued a report as a result of a worldwide survey. The purpose of the survey was to determine causes of the reported deterioration of Army Air Force materiel in the tropics. The principal problem contributing to deterioration was that storage conditions were entirely inadequate, with much materiel being stored outdoors. The mission found little or no deterioration in items properly stored in warehouses where ventilation was maintained. It found that there was no serious fungal damage to clothing except when packages were broken, damaged by rain, or stored improperly. Tentage was found to be affected both by fungus and ultraviolet light. Although fungicides improved fungus resistance, it was at the expense of resistance to actinic degradation. It concluded that the general causes of failure had been production of materiel designed for temperate climates, sacrifice of quality for quantity, shortages of proper materials, poor packaging and handling, inadequately trained personnel, and improper storage facilities.

In 1947, the jurisdiction of the British West African Tropical Testing Establishment (WATTE)[19], in Lagos, Nigeria, was transferred from the War Office to the Ministry of Supply. The military staff was supplanted by civilians with improved scientific qualifications. The staff was planned to include 30 members divided into five teams and separated by disciplines (chemistry, physics, electronics, light engineering, and biology). The goal of this reorganization was to improve upon the wartime WATTE by conducting a more fundamental research than was previously possible.

In 1947, the United States Army Air Forces Materiel Command[120] established an actinic test site for textiles, rubber, and aeronautical equipment at the New Mexico College of Agriculture and Mechanical Arts, Las Cruces, New Mexico. One of the

principal reasons for choosing this area was that the low relative humidity would discourage microbiological growth, and thus remove one factor that complicates the determination of the deteriorative effects of ultraviolet radiation.

In 1947, Leonard[72] described the Naval Research Laboratory Tropical Exposure Facilities at Fort Sherman, Canal Zone. The sites are the same ones described earlier by Teitell[111, 112]. Facilities were available for exposing articles in dense jungle (Skunk Hollow), to direct weathering by sun and rain (Fort Sherman Open Field site) or to marine conditions (Fort Sherman Breakwater). The history, scope of activities, and proposed plans were reported.

In 1952, the United States Army Chief of Staff became concerned with the narrowness of the test efforts of the Army Technical Services in the Canal Zone. Testing by the Corps of Engineers, Chemical and Quartermaster Corps, was focused solely on static materials exposure tests. A concurrence was reached among the DA General Staff on the requirement for a "United States Army Tropical Test Station" to perform not only corrosion studies but engineering and user tests of end items of materiel. Requirements were also projected for research in the medical, biological, physiological, and human factors areas. Planning was terminated in 1954 because of fund reductions. The requirement lay dormant until 1959 when the Army Scientific Advisory Panel strongly recommended a Tropic Test and Research Center. As a result, the United States Army Tropic Test Center (USATTC) was created in 1962.

In 1964, Dunn reported at the Thirteenth Conference on Prevention of Microbiological Deterioration of Military Materiel[86] on progress of the Joint Tropical Research Unit (JTRU) in Australia by discussing selected sites. The main site is at Innisfail and is in very heavy jungle, the Australian equivalent of jungle sites in Panama. Another site is at Cloncurry in a desert area, roughly equivalent to Yuma, Arizona. A permanent staff is not maintained at Cloncurry. Meteorological conditions of the two locations were described and compared with the previously used stations in Nigeria. It appears that solar radiation is about twice as great at Innisfail as at the Nigeria station at Port Harcourt. The seasonal temperature range of 15°F is greater at Innisfail than the 4°F range found in Nigeria. Comparing the hot-dry sites, average rainfall at Cloncurry is about half that of the Nigerian site and humidity is generally lower. Radiation is intense at both sites but is considered more severe at Cloncurry than in Nigeria. This was borne out by exposure trials. Materials deteriorated more rapidly in Australia than in Nigeria.

In progress at the time of the conference were tests on metal panels to assess the corrosion rate at both the Innisfail and Cloncurry sites. Tests were made on reveting material used to cover walls of trenches, and an exposure of polyethylene sheets. Many other items also were on exposure to include glass-fiber laminates, aluminum alloys, and paints. Site analysis was conducted by determining solar radiation profiles and temperatures of objects heated by the sun. It was reported common for a piece of metal on the ground at the desert site to reach a surface temperature of 160°F.

In 1968, Teitell[111] presented a description of tropic exposure sites at USATTC. He presented the background and objectives of various Frankford Arsenal studies on effects of tropic environments on materials, as well as a discussion of the geography of the Canal

Zone. He gave detailed information about the location, weather, and special environmental conditions at the various tropic sites used for materials exposure. Test sites included, on the Atlantic side of the Isthmus, marine (Galeta Point and Fort Sherman Breakwater), tree-shaded moist evergreen forest (Skunk Hollow), and an ammunition storage area at Fort Gulick. Described on the Pacific side are an open field site at the Chiva Chiva antenna field and a semievergreen forest at Albrook. An upland cloud forest site (semimontane), located near El Valle in the Republic of Panama at an elevation of 1000 meters above sea level, is described; the site is no longer in use. Teitell also described the results of specific studies of materials which were exposed at the various tropic sites.

At the Seventeenth Conference on Prevention of Microbiological Deterioration of Military Materiel[102] in November 1968, reports were presented by USATTC on an Environmental Data Base Project conducted for the Office of the Secretary of Defense and the US Army Chief of Research and Development. The project was limited to two Pacific side sites, Albrook forest and Chiva Chiva Antenna Field. Meteorological data, including temperature, relative humidity, and wind velocity, were measured at the surface and at eight different levels up to 150 feet. Evaporation, rainfall, cloud cover. and light intensity data were also collected. An intensive vegetation inventory of the sites was made and characteristics of the sites were determined for specific purposes. Measurements were made of both falling litter and litter found on the ground at various times during the year. Other measurements included a 1-year sampling of flying insects and a 2-year sampling of litter arthropods. Airborne microorganisms and microorganisms deposited on surfaces exposed to the environment were collected for a 2-year period. Paper tape and high volume samplers were used to take atmospheric samples of particulate matter and various chemical compounds of the atmosphere. In these investigations, dramatic diurnal and seasonal variations of atmospheric contaminants were noted.

b. Tropic Deterioration

- Plastics

In 1945, Lonsdale[73] reported on an exposure test of plastics made at the West African Tropical Testing Establishment. Various plastic materials were exposed for a 1-week period at indoor, open outdoor, forest, and swamp sites. Very little deterioration was noted, probably because of the short exposure period.

The Electrical Equipment Panel of the Great Britain Ministry of Supply published a paper[33] on the susceptibility of polyvinylchloride (PVC) materials to biological damage. It concluded that it was improbable that PVC materials could be of nutritional value to insects. It also concluded that PVC will support fungal growth but will not be seriously deteriorated by the growth.

Wellman and McCallan[118] studied the fungus resistance of plastics. Samples of plastics and components were inoculated with various tropical fungi.

Hutchinson[59] reported on the development of a method for testing the resistance of plastics to fungus attack. He commented that testing under simulated tropic exposure produced widely varying results, and involved too long an exposure time to be useful in routine acceptance testing. A laboratory method was developed using mineral salts agar so that fungus would grow only if the sample furnished the carbon source for the organism. Another method, sample weight loss evaluation was tried, but rejected because there was no correlation between performance deterioration and weight loss. Soil contact and soil suspension methods were tried, as well as a procedure using nutrient medium with and without preinoculation. All were considered unsatisfactory.

Brown[15] described Petri dish methods used for determining the resistance of plastic materials to fungus attack. In all five methods the fungus had to obtain the carbon necessary for growth from the plastic. He noted that many laboratories had installed tropical chambers as a first step in correlating Petri dish tests with the behavior in tropic areas. Actual exposure testing in tropic areas was cited as the second step. Tables were presented giving the fungus resistance of pure resins and various plasticizers. Most are resistant except cellulose nitrate, polyvinylacetate, melamine-formaldehyde polymers, plasticizers containing fatty acid derivatives and long chain aliphatic dicarboxylic acid derivatives.

Hutchinson[60] published an article briefly describing studies made at the University of Pennsylvania and in the Canal Zone. Sections were included on cork, plastics, and electrical and optical instruments.

In a 1947 report to the United States Joint Army-Navy Deterioration Prevention Committee's Seventh Meeting[7], Beckman discussed the climatic deterioration of plastics and plasticizers. He observed that these materials having the lowest moisture absorption also have the highest fungus resistance. In thermoplastics, the degrading component is usually the plasticizer. In general, hydrocarbon plasticizers are inherently resistant, whereas esters are less resistant. Extreme temperature effects are maximized in miniaturized electronic components that do not allow for the necessary heat dissipation. Resinous materials exhibited changes which apparently resulted from long exposure to natural influences.

In 1949, an exposure test of nylon cordage at Kanpur, India[110], revealed that deterioration, as measured by breaking strength, is rapid in the early stages of exposure and slows down during latter stages. Tensile strength fell almost linearly for the first 7 weeks and then gradually levelled off so that the percentage of original strength dropped only from 32 to 30 percent between the 19th and 32nd week. Solar radiation appeared to be mainly responsible for the degradation; associated factors such as rainfall appeared to contribute very little.

In the early 1950's, Yustein, *et al*,[125, 126], published the results of a study of outdoor weather aging of plastics. They exposed samples of various transparent plastic sheets, laminated materials, and molded plastic bars for periods up to 1 year in varying climates. Exposure site locations included Panama, New Mexico, New York, Canada, and Alaska. The materials included methyl methacrylate, cellulose acetate, allyl resin, vinyl

copolymer, cast phenolic glass-reinforced polyester, and phenol-formaldehyde laminates. After exposure, the samples were tested for mechanical, electrical, and optical properties. Cast phenolic sheets deteriorated more at tropic exposure sites than at other locations. For most other plastic sheets, tropic exposure was no more severe than temperate, subarctic, or arctic exposure and in some cases less severe. The temperate climate of New York accelerated the deterioration of cellulose acetate and cast phenolic because of atmospheric dust, smoke, and industrial gaseous pollution.

In 1952, Rauschert[91] evaluated plastic articles in the Amazon region. He found that PVC films gave good performance except for warping and staining. Nonpigmented polyethylene film was inferior, showing less resistance to handling and damage and becoming brittle after 2½ months of exposure to sunlight.

Quackenbos[87] investigated the migration of plasticizers in polyvinylchloride plastics. He found that the loss of plasticizer from vinyl film is controlled by diffusion within the film and volatilization from the surface. Of the two factors operating simultaneously, the rate of diffusion predominates when plasticized films are subjected to vacuum or immersion in soluble liquids. Where diffusion is the controlling factor, plasticizer loss is proportional to the square root of both time and film thickness. Diffusion increases with increasing plasticizer content and decreases with increasing film thickness. Escape of the plasticizer from the film surface controls plasticizer loss when the film is immersed in liquids in which the plasticizer is insoluble or in air.

In 1955, Feltman and Barrett[35] evaluated 76 plastic materials for outdoor weathering at temperate, subarctic, semidesert, and tropic sites, including Fort Sherman, Canal Zone. The materials included 4 thermoplastics, 18 thermosetting plastics, 30 cellulosics, 8 laminates and 16 elastomers, including 2 polyvinylchlorides and 4 polyamides. The materials were exposed in groups of six tensile bars and one hardness-electrical specimen. These were removed periodically up to 2½ to 3 years of exposure and examined for maximum tensile strenth, proportional limit, elongation at break, work to produce failure, apparent elastic modulus, hardness, and dielectric constant. Polyamides, such as nylon, were assigned a rating of class three, an indication that the material deteriorated seriously after short exposure. Polyvinylchlorides were assigned to class four, indicating that their weather resistance depended on the type and amount of fillers, additives and other compounding variables. The presence of a small amount of carbon black greatly increased the weather resistance of several plastics including polyvinylchloride. The semidesert site was found to be the most severe for materials subjected to ultraviolet light, including many cellulosics, polystyrene, cast phenolic and allyl resins, polyvinylchloride, and polymethyl methacrylate. Plastics subject to embrittlement by extreme cold, such as polyvinylalcohols and most molded phenolics, suffered their greatest deterioration at Fort Churchill, Manitoba. The Picatinny Arsenal site, where hot summers alternate with cold winters, caused the greatest damage in those materials susceptible to cyclic changes in temperature, such as some of the cellulosics and laminates. Of the 76 materials tested, only 18 suffered less than 50 percent loss in at least one measured property during 2½ to 3 years of exposure. Of these 18, six were thermoplastics, five of which contained an ultraviolet screening agent.

DeCoste and Wallder[25] studied weathering of polyvinylchloride, conducting both natural and accelerated weathering tests. They found that unprotected polyvinylchlorides degraded rapidly when exposed to the weather. Their conclusion was that exclusion of sunlight from the body of the plastic is the major problem in formulating polyvinylchlorides for outdoor use. They found that the best protection was obtained by addition of small-particle-size carbon black to the PVC.

Imoto and Ogo[61] studied the mechanics of photodecomposition of polyvinylchloride in a vacuum chamber using a mercury vapor lamp as a light source. The rate of decomposition was determined by pressure change due to liberation of hydrogen chloride gas. They found that the rate of decomposition reached a maximum after 15 minutes of irradiation and then gradually decreased. Stretching the samples briefly increased the decomposition for a short time. The activation energy for decomposition of the unstretched samples was calculated and found to agree with the activation energy for thermal decomposition. An equation was given for the volume of hydrogen chloride released.

In 1957, tropic deterioration of nylon filaments was the subject of a study of the British Tropical Testing Establishment[40] conducted in Nigeria. Monofilament specimens of nylon 6-6 and nylon 6-10 were exposed at four sites for a period of 2 years. Hot-dry (desert) conditions bleached nylon 6-6 and made nylon 6-10 yellow and opaque. Nylon 6-10 developed flaking and cracking under these conditions. Termites were found to cause damage to samples but there was no evidence that the material was consumed as a food source. Temporary changes in length were observed in nylon 6-6 but disappeared upon conditioning. At hot-humid sites there was a slight loss in tensile strength and elongation over the 2-year period and this was more apparent in the nylon 6-6. Under hot-dry conditions, tensile strength decreased to about one-fourth of its initial value and elongation decreased to about one-half its initial value over the same exposure period.

Bjorksten and Lappala[10] studied photo degradation in plastic films in Florida. A number of plastic films including polyvinylchloride were tested by stretching them with "moderate" tension over the top of open drums containing wet sand. The drums faced south at 15 degrees in Florida, 1 mile from the ocean. In sunlight, moisture was constantly evaporated from the sand, maintaining a temperature of about 135°F. Tensile strengths of the test strips after 6 months of exposure indicated that the presence of moisture during weathering has a profound influence on results, and that data taken on dry films were irrelevant when use entailed moisture or contact with water against one side of the film. Control films attached to plywood and masonite showed no deterioration after exposure for a year.

Hashimoto[49] studied the photochemical degradation of nylon 6 fabric by measuring intrinsic viscosity and amount of water-soluble material after irradiation up to 160 hours in a Fade-Ometer. The increase in water-extractables was approximately proportional to exposure time. After exposure, the intrinsic viscosity was higher than before. It was concluded that the molecular chains of nylon 6 are randomly split by exposure to light, confirming previous theories of random chain breakage.

In 1958, Korshak, Slonimskii, and Krongauz[68] studied the thermal destruction of nylon by heating it to various temperatures up to 330°C in a nitrogen atmosphere. They found that at 330°C equilibrium was reached and an insoluble polymer was formed. They concluded that the nature of terminal polyamide groups apparently does not affect the establishment of a constant molecular weight on heating in an inert medium, implying that actual destruction of the polymer is due solely to oxidation, though it may be catalyzed in different ways.

DeCoste, Howard, and Wallder[24] studied the effect of composition on the weathering of polyvinylchloride resins, using three series of compositions and exposing them in Florida, Arizona, and New Jersey for periods up to 6 years. They tested 15 plasticizers, five light absorbers, and two antioxidants in varying combinations and concentrations. They found that weatherability of a plasticizer depends on its inherent physical and chemical properties, as well as that of the stabilizer, pigments, and other ingredients. Plasticizers had a marked effect on weathering. More highly branched plasticizers were less resistant to weathering.

Voight[117] studied the photochemical degradation of unsaturated polyester resins by examining their ultraviolet irradiation spectra. He exposed films of the plastics to ultraviolet light in the absence of air. All substances developed a diffuse UV-absorption band with maximum extinction between 300 and 335 nm. After prolonged exposure, the band extended into the visible region, causing yellowing. If irradiation was carried out with wavelengths longer than 300 nm, the formation of the degradation band was completely suppressed.

Tamblyn, Newland, and Watson[109] studied methods of early detection of weathering damage in polyethylene. They presented three methods, formation of ketonic carbonyl groups, development of cracks on stressed specimens, and loss of tensile elongation. The first method did not always correlate well with the other two during outdoor weathering so it was judged impractical as a sole standard.

Bersch, Harvey, and Achhammer[9] studied the mechanics of heat and ultraviolet degradation in polyvinylchloride resins by subjecting them to the following sequence: (a) ultraviolet radiant energy in a vacuum at 45°C for 100 hours; (b) 100°C in vacuum for 100 hours; and (c) 100°C in air for 100 hours. The gaseous products evolved were analyzed by mass spectrometry. Changes in chemical structure were followed by infrared spectrophotometry. Benzene and acetone were produced in most cases. Susceptibility to degradation increased with increasing oxygen content and unsaturation of the untreated polymer.

Yustein[124] made photomicrographic studies of weather-aging of plastic materials exposed at a number of sites including Panama, New Mexico, New York, Canada, and Alaska. The combined effects of different climatic factors and prolonged exposure produced a wide variety of surface patterns. His results indicate that, for some plastics, 2 years of exposure in Panama is equivalent to 3 years of exposure in New York.

Hueck[58] studied the biodeterioration of plastics and reported that deterioration could be mechanical, chemical, or contaminative in nature. Causative agents included microorganisms, insects, and rodents. The polymers and plasticizers subject to microbial attack were listed with the comment that both chemical and physical attributes make them degradable. Examples of microbiological damage included mildewing and stiffening of polyvinylchloride, bacterial growth in plastic water pipes, and mildewing of paints. Damage by insects to plastics was discussed as well as rodent damage to electric wiring insulation.

Delfosse[26] studied the effect of plasticizer content on thermal aging of polyvinylchloride compounds. He found that before aging, decreasing plasticizer content shifted the yield point to a higher stress and decreased the elongation at break. After aging for 7 days at 100°C, the tensile curves indicated an increase in rigidity and the yield stress was increased, but the elongation at yield was only slightly lower. The elongation at break decreased considerably after aging but was affected less by the plasticizer content. These results show that the elastic properties of the PVC were not affected by thermal aging at 100°C for 7 days, but the plasticizer was greatly affected. Since the mechanical properties at the point of rupture were of little practical importance, it is suggested that the specifications be modified accordingly. As in polyethylene, the yield value, rather than the elongation at break, should be the basis for specifications.

In 1960, the British Ministry of Aviation[39] conducted a study on the weathering of polyvinylchloride in Nigeria, exposing 13 sheets of plasticized and four sheets of unplasticized polyvinylchloride and related materials at seashore, jungle, and desert sites. Dust and microbiological growth caused much staining of the material at jungle sites.

Chu, *et al*[18], conducted a study to determine the feasibility of utilizing ultraviolet light reflectance as a measurement of nylon fabric changes of deterioration when exposed to sunlight and heat. Samples were subjected to a variety of accelerated aging treatments which included outdoor exposure and exposure in a Weatherometer. Breaking strength was tested, as was ultraviolet reflectance at 260 nm, after each exposure. Correlation was 85 percent but variability was such that the confidence level for a 10± 1% loss in strength was only 38 percent. It was concluded that UV reflectance is a good screening test but is not sufficiently accurate to determine the exact amount of lost strength.

In 1964, Blahnik and Zanova[11] published a book concerning microbiological deterioration of plastic materials in which they gave experimental methods of testing plastics and varnishes against microbial attack. They also listed polymers and plasticizers with their resistance to fungal attack. Photomicrographs of various cultures and culture methods are shown. Wessel[119] published an article on the biodeterioration of plastics, giving a good description of the various kinds of attack. He pointed out that usually the biological susceptibility was due to a nonpolymer component. He noted that there was much confusion between deterioration of electrical properties and actual deterioration of the polymers, since most biological growth on plastics is actually at the expense of surface contaminants.

At the Thirteenth Conference on Prevention of Microbiological Deterioration of Military Materiel[86], the Joint Tropical Research Unit announced that they were studying plastics and rubbers in Australia, because of fungal degradation problems in various locations in the tropics. Tests on white plasticized polyvinylchloride showed excessive fungal growth on all materials except one, when exposed both in the open and in the jungle. The one exception was a specially formulated lot which contained no fungicide. This substantiated the claim that PVC is almost 100 percent inert to fungi. PVC will not support fungal growth, but when plasticizers, stabilizers and processing agents are added, it may become very susceptible to fungal growth, depending on what agents are used.

Sandoval[96] studied the microbial colonization of neoprene and teflon by sterilizing and burying them in soil. Following exposure, they were washed in successive baths of sterile water until the water was sterile after the washing. The samples were then plated on a nutrient medium and the microorganisms which grew were isolated and identified. A total of 310 isolates, including 156 bacteria, 102 fungi and 52 actinomycetes, were recorded. This was cited as evidence that so-called inert materials such as teflon and nylon apparently can be utilized by microbes.

A materiel test procedure was published as an interim pamphlet on Testing for Fungus Resistance[116]. It gave a discussion of considerations and test methods and procedures pertinent in the evaluation of the fungus-resistant properties of materials used in Army equipment. Lists of susceptible materials and materiel items are given.

At the Fourteenth Conference on Prevention of Microbiological Deterioration of Military Materiel[37], Teitell and Ross reported on their project that exposed 33 different molded plastics in the form of ASTM tensile bars. All the exposures were made at Galeta Island, Canal Zone, in sheltered, open, and soil burial. They found that correlation of visual microbiological activity with physical test data was not feasible for exposed samples on open racks because of periodic washout by rain. Visual assessment of deterioration was considered more reliable for samples exposed in the shelter than in the open. Some materials showed considerable growth of fungus but no change in physical properties. Urethanes showed fungal growth and definite changes in strength. Nylon 6 showed considerable loss in strength in soil burial. Nylon 6.6 showed much less loss, though still significant. It appeared that in nylon 6 there must have been some microbiological deterioration in the soil burial because chemical effects alone could not account for the loss in strength (43 percent). This effect did not show up in laboratory soil burial screening tests, showing that different phenomena are active in the tropics and that this is one advantage of field testing. Teitell commented that Panama was an ideal location to do tropical deterioration because of the succession of organisms that occurs each year which has an effect on deterioration that cannot be duplicated by artificial means.

In 1966, the Fifteenth Conference on Prevention of Microbiological Deterioration of Military Materiel[36], Ross described a plastic film test he had conducted in Panama. The purposes were (a) to obtain accelerated effects in connection with other studies, and (b) to conduct specific studies of thin films for various applications.

In a test in tropical India, Wroblewska[121] exposed four thicknesses of polyethylene at one site. Total solar radiation was recorded and plotted against time at monthly intervals. Solar radiation was much higher in the April–June period and was sufficient to cause complete destruction of the samples in 3 months. Exposure of the same type of samples during the part of the year with low radiation caused very little deterioration. The transmission of visible light of exposed samples was plotted against wavelength. Exposed samples showed a change in both total transmission and in the shape of the curve, indicating a color change. Changes in permeability to water vapor and carbon dioxide, breaking load, bursting strength, and Young's modulus were also measured. It was concluded that the deterioration process resulted from rupture of polymer chain bonds by ultraviolet light, followed by oxidation of the opened bonds by atmospheric oxygen.

Dolezel[28] published an article in Czechoslovakia on microbiological degradation of plastics and rubbers in 1966. In it he discussed the effects of bacteria, fungi, insects, and rodents, as well as methods used to protect such materials from attack by these organisms. Lists of polymers and plasticizers which are in common use were given, with comments on the materials' resistance to microbial attack.

- **Rubbers**

American studies of tropic deterioration were conducted by Hanson,[46] of Rock Island Arsenal, in the early 1940s. The materials studied were neoprene and natural rubber. Duplicate samples were stored in Hawaii and at Rock Island Arsenal for periods up to 3 years.

In 1948, Greathouse[41] published an article on the effect of microorganisms on rubber degradation. Microorganisms known to attack rubber include species of *Actinomyces, Proactinomyces, Micromonospora, Mycobacterium, Aspergillus, Penicillium, Pseudomonas,* and *Bacillus.* Their activity was indicated by oxygen consumption, carbon dioxide production, multiplication of microorganisms, and weight loss of rubber. Rubber products exposed to moisture under favorable conditions were especially susceptible. From experimental data it was estimated that up to one-half pound of rubber may be oxidized in 1 year in a 50-foot length of rubber garden hose if water is left standing in it. Rubber was found to be decomposed more rapidly by mixed than by pure cultures. Pure natural rubber was more susceptible to degradation than compounded products.

In 1952, Blake, *et al*[12], studied the microbiological deterioration of rubber electrical insulation. Sample materials included natural rubber, Buna, neoprene and butyl rubbers. Natural rubber and Buna were found to be inherently vulnerable to fungus attack. Neoprene and butyl were found to be more resistant. The fungus found to be most destructive to rubbers was *Spicaria violacea.*

Shraposhnikov[103] studied the growth of bacteria on rubber and found that the following were able to destroy the polymer: *Bacillus subtilis Achromobacter agile, Mycococcus rubber, Mycobacterium globiforme, M. laticola,* and *Actinomyces albus.* In all cases, growth proceeds at pH 7 or higher, a slightly alkaline reaction apparently being

preferable. Consumption of rubber by mixed cultures was found to be especially severe. Pure cultures quickly lost their ability to consume rubber in the laboratory, especially on a mineral medium with no other organic matter present except the rubber. In media richer in organic matter, the activity of the organisms was prolonged.

In 1953, Postouskaya and Kuzminskii[84] reported on the kinetics of oxidation of natural and synthetic rubber under the influence of light. Their studies indicate that the rate of oxidation remains constant with time over a period of 14 hours. The order of increasing steepness of the oxygen absorption versus time curve is: butyl rubber, butadiene rubber, and natural rubber. The curves for the first two materials level off after 13 hours. A decrease in unsaturation after 12 hours was 55 percent for photo oxidation and only 6 to 8 percent for thermal oxidation. Oxidation products were identified.

Turner and Kennedy[114] studied the microflora of natural rubber from Ceylon and found species of *Cladosporium, Helminthosporium, Syncephalastrum, Penicillium, Margaronomyces,* and *Bacillus.* This report confirmed the view that unvulcanized rubbers can support the growth of microfungi.

In 1955 Kaiser[67], working in Germany, reported on a test for crack growth in rubbers, very similar to the Ross Flexure test prescribed by ASTM D1052. This test is an aid to the quantification of oxidation and other kinds of embrittlement common to rubber.

Rook[92] reported on microbiological deterioration of vulcanized rubber in Holland. The strains tested were isolated from portions of a corroded Dutch pipeline gasket ring exposed on the inside to aerated tap water and on the outside to an anaerobic polder soil. Flasks with slices from the gasket ring were inoculated with separate strains of streptomyces and stored at room temperature for 12 months. One sample showed holes up to 1.5 millimeters in diameter resulting from microbial growth. Microscopic examination revealed filaments of streptomyces in these holes.

Bennicelli[8] and Heinisch and Kuhr[50] reported on studies of fungus resistance of natural and synthetic rubbers. Both found that the amount of fungal growth was dependent on the amount of nonrubber constituents present. Leaching of natural rubber to remove nonrubber soluble constituents decreased susceptibility to fungal growth.

Neu[77] reported on ozone resistance and weatherability of butyl compounds. He found that unsaturation of the polymer was the most important factor in ozone cracking. Variables studied included extent of cure, grade of polymer, type and concentration of carbon black, concentration of plasticizer, contamination by other polymers, and sulfur content. These were studied against a control rubber and exposed in an ozone chamber containing 50–100 parts per million ozone. Laboratory results were confirmed by exposure tests in Florida, Southern California, and New Jersey. Under-curing and over-curing led to severe cracking. The lower the unsaturation of butyl rubber, the better the ozone resistance. Slight contamination by other polymers decisively reduced the ozone resistance.

In 1958, Dunkel and Phelan[29] tested the resistance to ozone aging of several kinds of rubber including butyl and natural rubber. Criterion of performance was the time of appearance of the first crack. At room temperature and at 100°F, butyl rubber showed a marked decrease in resistance to increased ozone concentration. Natural rubber showed only small changes. The effect of extension became less important as ozone concentration increased. At higher ozone concentrations, butyl rubber was more affected by extension than natural rubber. Crack resistance of all polymers was independent of extension. Ozone resistance decreased as temperature increased.

Grossman and Bluestein[42] conducted a similar study on butyl rubber wire insulation stock. They tested the rubber in a chamber at 25°C with 0.01 to 0.50 percent-by-volume ozone. They found that at elongations below 200 percent, failure time was a rapidly changing function of elongation; at higher elongations, ozone failure time lost its elongation dependence. Ozone failure time of butyl vulcanizates was more highly dependent on ozone concentration than would be expected from simple ozonolysis of double bonds. A dual mechanism was proposed, consisting of ozonolysis of the unsaturated linkages and oxidation of activated sites in the polymer chain. At elongation below the critical elongation, (10 to 20 percent for the butyl studied) the applied stress was insufficient to cause cracking even after all available activated sites are oxidized.

Nette, Pomortseva, and Kozlova[76] studied the destruction of rubber by microorganisms and found that bacteria, fungi, *Proactinomycetes* and *Actinomycetes* can all grow on rubber under humid conditions. They found that rubber was actively destroyed by species of *Proactinomycetes* and *Actinomycetes* and that they could consume 20 to 40 percent of the rubber on which they were cultured. Bacteria were found to be much less active. Fungi were found to grow on rubber, presumably at the expense of nonrubber admixtures, but did not decompose the rubber polymer itself. They determined that in order to test rubber products for resistance to microbial attack it was necessary to use the *Actinomycetes,* bacteria, mycobacteria, and *Proactinomycetes.* The latter organisms actually destroy the polymer.

In the Thirteenth Conference on Prevention of Microbiological Deterioration of Military Materiel[86], Hutton enlarged on his discussion of the previous year, stating that in most of the exposure tests conducted by USATTC the short duration limited the detection of deterioration, and the vulnerability to attack went unrecognized. To an extent, the lack of realism in interpreting the results of environmental chamber testing can also exist in actual environmental testing. A proposed program was outlined which would gather sufficient information about the complete spectrum of meteorological conditions to assist substantially in understanding deteriorative effects of the environment.

In 1967, Iwamoto, Kikuchi, and Ooyama[64] tested the resistance of natural and synthetic rubbers to fungal attack in Japan, using calcium carbonate, clay, and carbon black as fillers. The rubbers tested were butyl, acrylonitrile, styrene-butadiene, neoprene, and natural latex. They found that the only rubber that would support fungal growth by this test was natural latex.

- **Metals**

In 1945, Larrabee[71] studied the corrosion of steels in marine atmospheres and seawater. He exposed duplicate steel specimens at stations throughout the world each year for 5 successive years. He found that the least corrosion developed in the dry inland atmosphere of Khartoum, Sudan, and that the most corrosion was observed at the heavily industrialized city of Frodingham, England. Corrosion was found to depend on the following factors: Moisture, temperature, and atmospheric contamination. At most locations, considerable variation was found in the weight loss of a succession of samples exposed during each of the 5 successive years.

Hudson[54] reported on the activities of the Joint Corrosion Committee of the Iron and Steel Institute and the British Iron and Steel Federation. One of their major concerns was the corrosion of iron and steel exposed without protective coatings. In this area the following facts were established or confirmed: The rate of corrosion of iron or steel varies with the intensity of the corrosive conditions; in the case of atmospheric exposure, the controlling factors were stated as relative humidity of the atmosphere and extent to which the atmosphere is polluted. The rate of atmospheric corrosion decreases with time. The effect of composition on corrosion resistance was proved to be significant only in the case of complete exposure to the outdoor atmosphere. When sheltered from rain, for example, no difference in low alloy steels and irons was observed.

Copson[21], in a study of the mechanism of rusting, found that the corrosion rate of steel depended on the quantity and quality of water in contact with the steel. The quality was affected by pollution, solubility of corrosion products, and by the washing effect of rain; the quantity was affected by the amount of rain, dew, the degree of shelter, and the porosity of the rust. Rain played a dual role-accelerating corrosion by providing the necessary moisture or retarding corrosion by washing away corrosive contaminants and corrosion products.

In 1948, in an investigation conducted for the British Railways, Dearden[23] attempted to correlate the corrosion of bare sheet steel with the amount of rainfall as registered by a raingauge. He carried out his investigation in the moderately industrial area of Derby, England, using steel panels. He found that only 35 to 40 percent of the corrosion occurred when the rainfall was sufficient to register on the raingauge. An additional 35 to 40 percent was attributed to the humidity, and the other 20 to 30 percent presumedly occurred during periods of drizzle and when the samples remained wet after recordable rainfall had ceased. A marked increase in the corrosion rate was noted when the relative humidity was over 80 percent. Corrosion was found to be greater on the underside of the samples, indicating that rainfall was not the dominant factor. Corrosion in a rural atmosphere was found to be 75 to 80 percent of that in Derby. No correlation could be established between the weather at the start of exposure and the subsequent corrosion rate. An annual cycle of rust-shedding was noted, with the rust adhering and attaining maximum thickness during February and March and about half of it flaking off in June or July.

Hudson[53] conducted atmospheric corrosion tests of iron and steel wires exposed for periods up to 10 years. He found that the corrosion rate was more affected by wire diameter than duration of exposure, with fine wires corroding more rapidly. Extent of corrosion was determined by corrosion, weight loss measurements and tensile tests.

Ogburn, Weaver, and Blum[82] studied the influence of relative humidity and surface contamination on the corrosion of AISI 1010 mild steel sheets. They found that surface contamination (by salt, fingerprints, etc.) was of greater importance in corrosion behavior than the relative humidity of the air in which the steel was exposed. A slightly contaminated steel surface corroded more rapidly at 20 percent relative humidity than a clean surface at 80 percent relative humidity. The corrosion-accelerating effect of salt residues was directly associated with their moisture absorbing tendency. Initial corrosion was rapid and diminished only after the entire surface was covered with rust. Seawater was found to be a more active contaminant than an equivalent salt solution. Corrosion behavior was evaluated visually, by weight gain and corrosion weight loss.

In 1952, Schikorr[99] reported on some factors which influence metallic corrosion as the inverse ratio of their intensity. That is, low concentrations of salts, acids, or water will accelerate corrosion of a certain metal whereas higher concentrations may actually reduce it. This inverse effect can occur in two ways: (a) the active concentration of a corrosive agent in the attacking medium may diminish, or (b) a protective coating may form on the metal surface. In salt solutions the rusting of iron is inhibited because the solubility of oxygen decreases as the salt concentration increases. Acids in general increase corrosion as their concentrations increase but iron in sulfuric acid shows an inverse effect to the extent that concentrated sulfuric acid is shipped in low carbon steel tank cars. An inverse effect is also noticeable in metals exposed to rain, especially in atmospheres containing corrosive substances that are washed away by rainwater. Rain may also act by favoring a protective film formation or washing away soluble corrosion products. Thus, steel samples exposed to the atmosphere in spring were corroded less at the end of 1 year than those which had been exposed only during the fall.

Filiform corrosion was the subject of articles published by Hargreaves[47,48]. His studies showed that incipient corrosion of steel often takes place by the formation of tracks. These tracks differ in width but each track is usually fairly uniform along its length. In laboratory tests, tracks were shown to grow from 0.003 to 0.005 centimeter per day. Exposure to air for 24 hours resulted in track formation on all samples, but when exposed to filtered air, no tracks were found at the end of 18 days. A specimen sprayed with 2 percent sodium chloride and 0.25 percent magnesium chloride solution, (similar to seawater) developed 60 to 70 corrosion tracks in 7 hours. Filiform corrosion could not be induced on steel which had been phosphated and given two coats of lacquer.

Hudson and Stanners[56,57] conducted atmospheric exposure tests at a number of locations in Great Britain, South Africa, and Nigeria. The exposed samples were steel panels coated with various metallic and nonmetallic coatings. One of the results of this investigation was that a polluted industrial atmosphere in a temperate location was about as corrosive to painted steel as a rural tropic atmosphere. In a later investigation [55], the

same researchers conducted a systematic study on the effect of small amounts of alloying elements on corrosion resistance of 60 mild steels in industrial atmospheres and in seawater over a 5-year period. Laboratory salt spray tests were also conducted to compare reproducibility of results. It was found that low-alloy additions gave considerable protection against atmospheric corrosion. On immersion in seawater there was less improvement in protection with small alloy additions. Carbon content was not found to be a major factor in corrosion resistance of structural steels, nor was heat treatment in tests of long duration. Laboratory tests of the intermittent spray-type yielded only a fair correlation with the results of outdoor exposure.

LaQue[70] and Larrabee[71] separately reported on corrosion of steels in 1953. Both investigations linked corrosion severity to environmental variables, including atmospheric salt or salt spray, sulfur dioxide from industrial pollution, and moisture. Both found also that alloy additions were useful in increasing resistance to atmospheric corrosion, especially if associated with industrial pollutions.

In 1955, Ambler and Bain[2] investigated atmospheric corrosion of several common metals at more than 20 sites in Nigeria and others in England, Wales, Australia, North Carolina, and Malaya under various conditions of atmospheric humidity and salinity. They found that corrosion was generally no higher under tropical conditions than in temperate climates. Where there was no industrial pollution, the governing factor was found to be airborne salt. While steel may corrode at the rate of 48 mils-per-year (mpy) in very saline atmospheres, the rate may be only 0.6 mpy in very humid areas free from salt. They found the rate of corrosion for ferrous metals varied little between wet and dry seasons or between day and night. They measured atmospheric salinity by various methods, and the corrosion of ferrous metals was found to be proportional to the atmospheric salinity. In saline or polluted areas corrosion proceeded at approximately a constant rate, but in unpolluted inland areas the initial slow corrosion slowed even more after 1 month and almost ceased after 6 to 9 months. It was stated that salt particles in sizes above 10 microns caused most of the corrosion. Smaller particles appeared to have little or no effect.

The preceding comments are further borne out by Evans[34] in a paper dealing with chemical changes occurring at the surfaces of metals undergoing corrosive attack. He stated that metals usually undergo atmospheric corrosion if the relative humidity exceeds a certain critical value. Acidic sulfur compounds or particles of salt accelerate this attack.

Preston and Sanyal[85] showed that metals display filiform corrosion when contaminated by nuclei in a humid atmosphere, and that with some kinds of nuclei this corrosion will take place at relative humidities below 60 percent. Chlorides and sulfates provide the most active nuclei followed by nitrates and acetates. Most salt nuclei produce deep tracks interconnected by pits at short intervals.

Holzwarth, Thomson and Boegehold[52] conducted a study on the nonprotective rust formation on automobile body sheet steels. They noted that corrosion of automobile bodies was generally the result of nonprotective rust formed in sheltered areas, such as inside fenders and doors. X-ray diffraction studies showed that this nonprotective rust

was 80 to 90 percent magnetite and 10 to 20 percent ferric oxide-monohydrate. Rust from openly exposed areas was more adherent and protective in nature and was composed entirely of ferric oxide hydrates. They developed a 20-day cyclic humidity-accelerated corrosion test to reproduce the sheltered type of corrosion.

Eisenstecken and Stinnes[32] studied the effect of trace impurities in low carbon steels in rural and industrial atmospheres in Germany and in total and alternate immersions in seawater and tap water. The elements studied were copper, manganese, phosphorus, and sulfur. It was found that in steel compositions normally used manganese, phosphorus, and sulfur had very little effect on rate of corrosion. Copper in the amount of 0.6 percent was found to be beneficial in the presence of atmospheric sulfur by the formation of protective film.

In 1956, Sanyal and Singhania[98] studied seasonal variations in the corrosion of steels and zinc in India. They found appreciable corrosion during the winter and rainy season (7 months). The rate of corrosion fell and was almost negligible during the driest months (May and June). The yearly average corrosion rate for steel was 0.9 mil-per-year at a semiindustrial site near Kanpur and 0.2 mil-per-year at Delhi. Mild steel samples exposed initially during the "nonaggressive" months (March–April) showed lower yearly corrosion rates than those started in more corrosive months. They found a high correlation between rate of corrosion and humidity; rainfall and dew were contributory factors. Exposure conditions determined the rate of corrosion at each site; the fully exposed condition gave maximum corrosion, with less corrosion in partly sheltered outdoor exposure. Specimens exposed vertically corroded less than those exposed at an angle of 45 degrees. Minor variations in steel composition had no influence on corrosion rate.

Dychko and Dychko[30] studied atmospheric corrosion of metals at low temperatures to verify a hypothesis that metals corrode more rapidly at low winter temperatures than at higher summer temperatures. The hypothesis was rejected because atmospheric corrosion slowed down below 25°C because of decreased chemical activity of metal surfaces and delayed action of electrochemical processes.

Iofa and Besproskurnov[63] made a study of the mechanism of the atmospheric corrosion of iron in the presence of sulfur dioxide. They used Armco iron, equivalent to an AISI 1004 steel, and exposed the laboratory samples over solutions which gave atmospheres of various concentrations of sulfur dioxide. The corrosion rate decreased with decreasing relative humidity and became practically insignificant at 65 to 70 percent relative humidity. The retarding influence was traced to rust which formed after 25 to 30 hours in moist air. Rust layers were thicker with higher sulfur dioxide concentrations.

A 16-year project carried out in the Canal Zone by the Naval Research Laboratory[108] exposed a wide variety of metal samples in five tropic environments: fresh water, seawater, seawater mean tide, marine atmosphere, and inland atmosphere. For each type of metal samples, corrosion versus time were plotted for each site. Results were compared among sites and with results from temperate climates. Length of exposure was found to have a considerable effect on corrosion rate in atmospheric exposure. Samples

exposed at the inland Miraflores site for the first year showed a corrosion rate of 2.8 mils-per-year but the average for an 8-year exposure dropped to only 1.57 mils-per-year. A similar effect was found at the more corrosive Cristobal site, on the Atlantic Coast, where the first year's exposure produced a rate of 5.1 mils-per-year, while the 8-year average was only 2.55 mils-per-year. The decrease is attributed to the protective effect of accumulated corrosion products.

In 1958, an investigation was conducted by Frant[38] into the validity of salt-spray testing in laboratories. The test samples were tin-plated copper, and a group of 80 specimens were tested at 15 different test stations. Significant differences were found in corrosion results, not only from one laboratory to another but from one location to another in a given salt-spray cabinet.

On the basis of a 25-year program, a corrosion map of the United States[94] was published in 1958, showing the number of years and months required to corrode a 28-gauge low carbon steel panel to a severe degree. The program was conducted in 523 cities of more than 10,000 population each. The length of time required to produce this result varied from 3 years in Buffalo, New York, Erie, Pennsylvania, and Miami, Florida, to more than 15 years in Tucson, Arizona.

Mikhailovskii and Tomashov[74] and Tomashov and Lokotilov[113] did research on the mechanics of atmospheric corrosion, studying electrochemical effects and adsorption of moisture. They found that a water film adsorbed on a metal surface does not constitute a barrier for the diffusion of oxygen. They found, also, that the thickness of the adsorbed film varies with relative humidity, from 15 molecular layers at 55 percent relative humidity to 92 layers at 100 percent relative humidity. A comparison of a moisture adsorption isopleth with data obtained in electrochemical measurement of atmospheric corrosion showed a direct relationship between the adsorption of moisture and the corrosion rate.

Hache[45] studied atmospheric and immersion corrosion in France. Although most of his samples were stressed to 75 percent of the elastic limit, he found that the stress level had no significant effect on the corrosion behavior in either atmospheric exposure or immersion. He found that in a highly corrosive industrial atmosphere, Bessemer steel was more susceptible to corrosion than was open hearth steel.

Schikorr[100] published an article on the diagnosis of the causes of corrosion processes from corrosion products. His conclusion was that although other data about corrosive conditions are usually necessary to pinpoint the causative agent, examination of composition, distribution, solubility, and crystal structure of corrosion products can provide valuable information on corrosive attack.

In 1959, Byalobezhskii[17] studied the effects of radiation on atmospheric corrosion and arrived at unexpected initial results. Low levels of radiation intensified the corrosion and higher levels reduced corrosion. Further examination revealed that the higher levels of radiation heated the samples and drove off the surface moisture films. The corrosion intensifying effect of the low-level radiation was found to be due to the presence of corrosion-accelerating irradiation products of oxygen, water, and nitrogen.

Sanyal, *et al*, [97] evaluated the corrosion of mild steel at Bombay, India, in an industrial marine atmosphere for outdoor and indoor exposures. They found that the rate of corrosion increased with an increase in humidity, salinity, and amount of rain. They found no effect from sulfur dioxide. They determined that the corrosion rate of mild steel indoors was about one-third that of the outdoor rate.

Grumbles and Moore[43] in a study for the Texas Highway Department exposed sandblasted 12-gauge steel highway marker stock to varying atmospheric conditions. Losses in weight were determined at intervals up to 400 days. Weight-loss curves for all panels except those exposed over saltwater were smooth and continuous with a gradual decrease in slope with time. This was attributed to the adherent coating of rust on the steel surface which afforded some protection from further corrosion. Chloride content of the rust from a Corpus Christi site averaged 0.07 percent while that from other coastal sites averaged 0.03 percent.

Rajagopalan, Sundaram and Annamalai[90] studied the corrosion of metals at Mandapam Camp Testing Farm in India, determining monthly corrosion rates at two sites near the ocean. One was 150 feet and the other 1350 feet from the water. Material was exposed under both open and sheltered conditions on racks facing 45 degrees south. They found no direct relationship in sheltered exposure between corrosion rate, distance from the sea, and atmospheric salinity as measured by the wet candle method, but salinity was found to be an important factor in determining corrosion rate under open exposure conditions. A small increase in mean temperature caused considerable acceleration in the corrosion rate in the open when accompanied by both high humidity and high salinity.

Yocum[123] published a review of the deterioration of materials resulting from atmospheric pollution. Noted were the effects of sulfur oxides on metals, textiles, and other materials; hydrogen sulfide on metals and paints; ozone on polymeric materials, textiles, and dyes; and particulate matter on various types of materials. Weather and topographic effects on atmospheric pollution were briefly discussed.

An analysis of the materiel deterioration problem was published in 1959 by Bloch[13]. He stated that environmental engineering had not developed the knowledge needed for the design of products which would serve their intended purpose under any specific climatic conditions. At that time only long-term exposure of new products to critical environments provided reliable information on the suitability of an item for use under specific climatic conditions. Bloch believed that before environmental resistance can be designed into a product, the exact mechanisms must be known. He outlined 20 projects by which he felt the mechanisms of deterioration could be determined. With the knowledge provided by the results of these projects, he believed undesirable deterioration could be entirely eliminated or considerably reduced.

Babakov and Tufanov[3] exposed sheets of 38 different heat-treated steels in polluted and pure air outdoors at 30°, facing south. Weight losses were periodically determined, and in polluted air the rate was about three times higher than in pure air. Results were obtained for 1 to 5 years of exposure. The composition of the steel

appeared to be the most important factor contributing to corrosion resistance. In polluted air, the corrosion rate decreased with increasing carbon content; in clean air, carbon content had no effect. The corrosion rate of carbon and low alloy steels decreased with time. After 5 years, the rate was about half that of the first years' exposure.

In 1964, Hutton[86] described his work with vacuum evaporated metal films. He was able to demonstrate both in the laboratory and in the forest that the atmosphere over normal forest litter affected the films only if there was sufficient temperature cycling to produce wetting and drying of the surface. When the experiment was performed with sterile litters or if only high purity distilled water was in the system, there was no deterioration of the films. Since substances dissolved in water become more concentrated as the water evaporates, the equilibrium of the solution shifts in the direction of concentration of the less volatile substances. A natural cyclic phenomenon occurs by this mechanism which causes any exposed surface in the tropics to develop an ever increasing layer of whatever materials happen to be in the air. It was hypothesized that these materials could serve as nutrients for fungi. Thus, almost any exposed surface should become a substrate for fungi after sufficient exposure to the atmosphere.

In 1968, Guttman and Sereda[44] conducted a study on the atmospheric factors affecting the corrosion of metals. The factors studied included time of wetness of metal panels, panel temperature, atmospheric sulfur dioxide, and atmospheric chloride content. Samples were exposed and both atmospheric and corrosion data were obtained for four inland and three coastal North American Sites (Cleveland, Ohio; two sites at Kure Beach, North Carolina; Ottawa, Ontario; Fort Sherman open site, *Canal Zone*; South Bend, Pennsylvania; and Trail, British Columbia). Panels exposed were of steel, copper, and zinc. Corrosion losses of panels exposed at different times of the year showed considerable variation at all sites. Statistical analyses showed conclusively that the atmospheric factors completely controlled the corrosion rates at all sites tested for at least the initial month. For longer periods of time, control of the corrosion process remained with the atmospheric factors in some cases and in other cases it was gradually transferred to factors related to the changing surface conditions resulting from accumulation of corrosion products and foreign agents.

- **Textiles**

In 1945, the Royal Aircraft Establishment[93] published notes on the development of a test for the quantitative assessment of microbiological degradation of cotton. It studied the index of refraction of fibers perpendicular and parallel to the axis of the fiber, and found that both indices decreased as a result of attack by microorganisms.

Klemme, *et al*[68], studied the effect of laboratory exposure of cotton to 43 fungi in a mineral salts liquid medium containing ammonium nitrate. Many of the fungi used were obtained from mildewed cotton fibers, fabrics and other cellulosic materials. Twenty-nine of the fungi produced breaking strength losses of more than 50 percent in seven days.

Similar test methods were described by Siu and White[105] in a summary of the work done at the Tropical Deterioration Research Laboratory of the Philadelphia Quartermaster Depot. Most of the work consisted of isolating and identifying fungal and

bacterial cultures and evaluating treated materials with various microorganisms. Mechanics of deterioration of cotton fibers by fungi and bacteria were also studied. It was found that fungal hyphae entered the lumen of the cotton fiber by direct penetration of the primary and secondary walls. Bacteria, on the other hand, adhered to the outer surface of the fiber and penetrated inward.

Zuck and Diehl[127] conducted a study on the fungal damage to sun-exposed cotton duck in which they found certain angiocarpous fungi were significant agents in the slow cellulosic breakdown of fabrics during atmospheric exposure. These fungi were representative of saprophytic flora of dead plant stems and leaves which had previously escaped detection in textile deterioration work. The slow growth of fungi did not show up with standard plating techniques and were developed on fabrics only after long periods of exposure. At 45° south angular exposure of the cotton duck, the upper surface of the fabric showed little evidence of fungal attack, but there was considerable discoloration on the lower side. This unequal distribution of colonies was attributed to lethal radiation of the sun which prevented hyphae from growing at or near the upper surface. Since many of the hyphae were within the lumina of the fibers, much of the nutrient was probably supplied by the remains of protoplasmic action. However, visual, chemical and mechanical tests indicated that certain areas of the fabric remained relatively undamaged after 18 months of exposure.

In 1946, Barghoorn[5] reported on a study of tropic deterioration of cotton fabrics with various treatments and preservatives. Samples were exposed at Barro Colorado Island, Canal Zone; Fort Sherman, Canal Zone; Oro Bay, New Guinea; and Homestead Army Air Base, Florida. The fabrics were exposed in continuous sunlight, continuous jungle shade, soil contact, soil burial, cycled sunlight, shaded and damp storage, and cycled shaded and damp storage. After exposure, the samples were tested for breaking strength, hydrogen ion activity, and changes in solvent viscosity. The relative importance of physical factors, principally ultraviolet radiation, and the microbiological factors of degradation of cellulosic textiles in humid tropic climates were studied. The importance of solar radiation in tropic deterioration was emphasized, particularly with regard to the acceleration of deterioration by ultraviolet light in the presence of fungicides. Continuous exposure of fungicide-treated fabrics for 8 to 12 months in tropic sunlight was found to be far more destructive than exposure to conditions fostering microbiological deterioration; i.e., without addition of fungicides to fabrics. Samples subjected to sunlight exposure showed the greatest decrease of pH. This was attributed to (and correlated with) the photochemical instability of fungicides. Actinic degradation caused increases in cuprammonium fluidity (a standard test for cotton) which was well correlated with breaking strength measurements. Under microbiological deterioration no significant change in fluidity was observed although breaking strength decreased. The data in general showed a negative correlation between fungicidal effectiveness and resistance to tropical weathering.

Dean and Warner[22] investigated the degradation of untreated cotton fabrics weathered in the New Orleans, Louisiana, area. Average effects were determined by combining data obtained from replicate samples exposed for equal periods to different sequences of seasonal conditions. Changes in breaking strength and cuprammonium

fluidity were the chief criteria used in determining the extent of degradation. Unbleached 10-ounce cotton duck lost about 40 to 45 percent of its strength after 6 months of exposure and 60 to 65 percent after 12 months. Unbleached lighter weight fabrics showed somewhat greater losses.

In 1949, Race[88] studied the degradation of cotton in atmospheric exposure in industrial regions of England. He found that air and sunlight were the chief causes of degradation of weather-exposed cotton during the summer, but acidic atmospheric moisture was more destructive during winter. The least deterioration occurred in autumn and spring. The mechanisms of chemical and photochemical reactions were discussed. It appeared that oxygen in the absence of light was not harmful. In winter the pattern of deterioration suggested a mechanism resulting from sulfuric acid released into the atmosphere by the high domestic coal consumption in the area.

In 1951, a study conducted by Yelland[122] consisted of exposing tentage fabrics in Virginia and Florida. Although these were not tropical conditions, it is reported because high correlations were obtained with measured meteorological conditions. Temperatures inside the tents, total solar radiation, and radiation in the ultraviolet, visible and infrared regions were measured. Results with several types of materials were correlated to the solar radiation received upon atmospheric exposure.

Abrams[1] studied the mildew resistance of weathered 8-ounce cotton duck at Charlottesville, North Carolina, exposed for 2 to 8 months. He found that the material was more resistant to *Chaetomium globosum* sp. than similar unexposed fabrics. Disregarding the strength loss due to weathering, the resistance to fungus of the exposed fabrics increased up to the 4th month, after which it remained constant through the 8th month. A possible explanation presented was that the amorphous cellulose component of the fiber was deteriorated rapidly by photochemical action, leaving the more resistant crystalline structure cellulose of the cotton exposed.

In 1953, Bakanauskas[4] studied the outdoor weathering of synthetic fibers in comparison to cotton. Samples exposed included nylon 201, orlon 81, dacron 54, dynel, acrilan, rayon and cotton. Atmospheric exposure was at 45° facing south. Acrilan and dacron were the only synthetics that had better weathering resistance than cotton. Soil burial tests substantiated the susceptibility of rayon and cotton to fungal attack.

Boneh[17] studied the capability of various fungi (*Penicillium, Trichoderma, Stemphyllium, Alternaria, Stachybotrys, Memnoniella* and *Chaetomium* species) to destroy cellulose. He found that the genus *Chaetomium* caused the most severe damage to cotton tentage fabrics. Microscopic examination showed that the intensity of cellulose decomposition was directly related to the extent of hyphal penetration of the fibers. The external layer was only damaged at the point of penetration where the wall was dissolved. The hyphae grew through to the lumen where they developed and branched. Subsequently the walls were completely decomposed, the extended lumen became filled with hyphae, and only the waxy shell remained intact. *Chaetomium* was also found to be moderately fungistatic to other genera.

Hessler and Upton[51] studied the effects of weathering on open cotton bolls in cottonfields. The bolls were left in the field for intervals up to 5 months, beginning in September and November. All weathering was under dry conditions. No evidence of decay was found, but exposure affected the fiber through loss of low molecular weight materials other than cellulose. Changes in the cellulose molecule itself were due to chain rupture and oxidation, determined by cellulose nitrate viscosity tests. Field weathering also decreased dye uptake by the cotton. Polar substituent groups in the cellulose molecule are believed responsible for the difference in dye uptake.

A similar study was conducted in Russia by Kadyrov[66]. He found that raw cotton exposed to the action of sunlight and other atmospheric factors decreased in tensile strength, elongation and degree of polymerization. Cotton removed from the bolls and exposed in the open air for 38 days exhibited a 37.7 percent loss in tensile strength and a loss of elongation of more than one-third. Tensile strength was at a maximum on the 7th day after opening of the bolls, with a rapid decrease upon longer exposure. Degradation was also explained by chain rupture.

In 1956, Norkraus and Ranby[79] studied enzymatic degradation of cellulose in Switzerland using enzyme preparations from *Streptomyces* and four different hymenomycetes. Enzymatic activity was expressed in terms of reducing substances, glucose formed and changes in the degree of polymerization. Expressed in terms of reducing substances, chain rupture occurred in less than 65 percent of the inital amount of cellulose. The limit seemed to be related to the morphological structure of the cellulose rather than to enzyme activation.

Baskin and Kaplan[6] attempted to prepare a mathematical model of microbiological deterioration of fabric samples exposed in jungle shade. The data fit best to a second order polynomial with three constants. At an exposure site in Louisiana, the deterioration curve had two parts; a sharp linear drop in strength followed by a more gradual change. The initial drop was ascribed to a photochemical reaction with the dye in the fabric, and the second to biological attack. In soil burial tests, the deterioration occurred in three phases, each best fit by a different polynomial, due perhaps to different dominant biological species, or to attack on different parts of the cellulose structure.

In 1958, Smith[107] studied the natural weathering and indoor storage resistance of Air Force cotton webbing yarn and fabric panels in South Florida. The materials were exposed for 12 months to direct weathering inland at 45° facing south. Webbing rolls and cloth rolls were exposed to indoor open-shelf storage for the same period. Samples were inspected monthly for color change and fungus growth. Climatological data were recorded daily. In outdoor exposure, varying degrees of degradation were noted. All samples, however, were bleached or severely faded after 12 months. No fungus growth or apparent tendering was noted on any of the fabric panels. There was no apparent degradation on any of the specimens stored indoors for the 12-month period.

Nopitsch and Mobus[78] published the results of a study of various strains of the well-known fungus, *Aspergillus niger*, and its ability to destroy cellulose. Strains of *Aspergillus niger* from Europe and America were used. They inoculated linen and found

that all cultures except one from Holland caused considerable tensile strength loss to the fabric; losses ranged from 6 to 100 percent. Microbial action on cotton was mild compared with action on linen resulting in strength losses from 0 to 41 percent. An American strain exhibited the strongest cellulolytic action, with strength losses ranging from 41 percent for impregnated cotton to 100 percent for linen samples. The results suggest that fungi from different locations may show variations in destructive ability toward cellulose.

Simpson and Marsh[104] also conducted research on *Aspergillus niger* and cotton. Their samples were plated on mineral salts agar to which varying amounts of glucose were added. At suitable glucose levels, distinct tensile strength losses were produced in the cotton strips. The degree of swelling of fiber from the strips in concentrated alkali increased during incubation. When several of the black *Aspergilli* were tested over a range of glucose concentrations, the changes in alkali swelling closely paralleled the strength loss. Both properties were considered to reflect cellulose decomposition, the alkali swelling being the more sensitive property.

Sadov and Vylcheva[95] studied the action of light on cottons after various bleaching and other cleaning treatments, exposing them to sunlight for 4 months in the summer. Chemical analyses carried out on a regular basis showed that both primary and secondary hydroxyl groups of cellulose were oxidized to aldehyde and ketone groups. Viscosity and tensile strength measurements indicated that hypochlorite-bleached cotton was the least resistant to sunlight.

The Indian Standards Institution[62] published a method for detection and estimation of damage in cotton fabrics due to microorganisms in 1959. The prescribed examination involved visual examination and testing of samples for strength and pH. Photomicrographs were presented illustrating various degrees of fiber degradation.

Raes, Nicolaus and Fransen[89] studied test methods for evaluating microbial attack on cotton. Many previous tests used to measure degradation of cotton, such as measurement of degree of polymerization, pH, and copper reduction value, did not measure characteristics necessarily related to biological degradation, and thus may yield erroneous conclusions. Other methods, such as ultraviolet luminescence and staining reactions indicated presence of contamination but do not determine extent of deterioration. Methods based on swelling of fibers in alkali, particularly the "alkali centrifuge value" (ACV) test, which is a function of the specific surface of the fibers, appear to correlate better with the degree of biological degradation. The authors investigated the relation between ACV and the specific surface of normal and degraded cottons. A series of cotton samples, some of which were deteriorated to strength losses up to 26 percent, were used. Determinations of pH and copper reduction value of the samples were also made for comparison. For nondegraded samples, the relation between ACV and the specific surface was linear. These samples had a pH of approximately 7 and copper reduction values of 0.6 to 0.9. For degraded cottons, the relation between ACV and specific surface was nonlinear. The ACV for these samples was higher, the increments of ACV being related directly to the amount of strength lost. The reliability of the ACV test as a means of evaluating the degree of biological degradation of cotton was confirmed by a series of tests on cotton samples showing various degrees of microbial contamination.

Morris and Wilsey[75] studied the effect of three soiling agents on the photochemical degradation of cotton. Yarns were impregnated with airborne soil collected from air filters in buildings, a ground soil (clay loam), and a lignin derivative extracted from clay loam. After exposure to a carbon arc light source for 320 and 640 hours, degradation was measured by fluidity and tensile strength determinations. Fluidity measurements indicated that the airborne soil accelerated photochemical degradation but the ground soil and lignin derivative did not. No difference in breaking strength values was found with any of the soils.

In 1964, tests of copper-zirconium treatment for solubilizing antimicrobial agents for cotton were reported by Kaplan[86]. Of interest here are the results of his control data. A grey cotton duck material was considered a representative material and was used in the tests. Samples were exposed to soil burial, leaching, and atmospheric exposure. Both treated and untreated cotton duck were then exposed at Fort Sherman open and forested sites in the Canal Zone. In the forested site, both untreated and treated samples gained strength in the first 2 months and then lost strength (the untreated rapidly and the treated more slowly). In the Fort Sherman open site, both materials produced an almost linear drop in strength, with the treated material dropping to slightly more than half its original strength and the untreated to slightly less than half.

Between 1964 and 1969, sandbag testing was the subject of discussions at the Fourteenth, Fifteenth, Sixteenth, Seventeenth, and Eighteenth conferences on Prevention of Microbiological Deterioration of Military Materiel[37, 36, 106, 102, 31]. One hundred sandbags of 12 different types were exposed at four locations in the Canal Zone. Fort Sherman open site, Fort Sherman forested site, Galeta Point marine site, Chiva Chiva open site, and Empire Range grassland site were selected by the US Army Tropic Test Center. The bags were exposed singly on the ground and in a simulated revetment type exposure. They were examined monthly for deterioration by fungi, insects (termites), rodents, and also for actinic degradation. A smaller series of bags was placed at the Yuma Proving Ground Desert Test site in Yuma, Arizona. Principal attention was given to the performance of the general polymeric materials under atmospheric exposure. A third series was designated for troop use at Fort Benning. This series was expected to show military potential under simulated infantry combat conditions. Resistance to small arms fire and immersion in water was also studied. Fungus attack of fabric, thread, seams, or tie strings; attack by insects, termites, or rodents; mechanical damage attributable to manufacture; solidity of fortifications; and slipping or sliding of sandbags were evaluated. In 14 months of exposure at Yuma Proving Ground, polyethylene, polypropylene, and cotton bags had failed to meet established criteria but several types of acrylic bags and PVC-coated fiberglass bags were still in satisfactory condition. In the Canal Zone, knitted polypropylene bags failed rapidly at Galeta, Fort Sherman open, and Chiva Chiva sites and some failed at the forested site after 10 months. Monofilament polypropylene bags started to fail at 4 months in sunlight and all had failed at 11 months. Most of the monofilament polypropylene bags at the Fort Sherman site were still in good condition after 12 months of exposure. Polypropylene multifilament bags began to fail after 7 months in sunny sites and all had failed in these sites by the 11th month. High density polyethylene bags began to fail after 6 months in sunlight and all had failed after 11

months. Some of these bags deteriorated following 12 months of exposure in the jungle area. PVC-coated fiberglass bags showed a high failure rate at all sites after 2 months. All types of acrylic sandbags were in good condition after 12 months of exposure. Almost all cotton bags failed in the jungle, and some at other sites, after 8 weeks. After 24 weeks, all of the exposed cotton bags had failed. Sandbag tests were completed in 1967 and results reported in the Eighteenth Conference on Prevention of Microbiological Deterioration of Military Materiel.[31]. The only synthetic bags surviving after 2 years of exposure were the acrylic bags. Considerable discussion was concerned with the deterioration of synthetic materials at the forested site. No satisfactory explanation was advanced.

4. SUMMARY OF RESULTS

Tropic exposure sites have been established since 1945 in such countries as Australia, India, Nigeria and Panama, and have played a key role in the solution of problems associated with tropic deterioration. These sites offer a unique environment, which thus far has not been successfully simulated, in which to study the effect of deterioration of materials exposed to the effects of the humid tropics.

Results of the survey of Programs in Tropic Materials Research are as follows:

- **Plastics**

Much research in the past quarter century has been directed toward the development and improvement of plastic materials. The word plastic as commonly used is a noun describing a class of synthetic or natural materials, capable of being shaped when soft and of assuming a relatively rigid structure when hardened. Although many plastic compounds of natural origin have been known for centuries, today the word plastic includes compounds containing stabilizers, fillers, plasticizers and resins. Every plastic material by varying the composition of its additives has characteristic properties which affect its performance when subjected to tropic exposure. Tropic environmental testing on plastics has been conducted on such material as cable, pipe, fabrics, sheets, and laminated structures. The various types of plastic material exposed to the environment have included polyvinylchloride, polyvinylacetate, polyamides, polyolefins, and cellulose acetates. Investigations in tropic deterioration during the period this survey covers, have determined that most non-compounded plastics are fungus resistant but are quite susceptible to deterioration by heat and light. Further investigations revealed that fungus growth was most prevalent on plastics which were allowed to develop environmental film coatings. Thus, it was found that biologically inert material such as PVC or teflon could and does in fact, serve as a substrate in which microbial growth can occur. In general, plastic materials which contain natural substances, such as animal or vegetable products, are much more subject to destructive fungal growth (as opposed to superficial growth on environmental film coatings) than those which are of completely mineral origin.

- **Rubbers**

A common phenomenon of many rubbers in tropic exposure during World War II was the physical indication of cracking and blistering. If the rubber was under stress,

then straining and elongation had a direct relationship to this condition. Degradation of rubber has been attributed to light, heat, moisture, and atmospheric oxidation; and oxidation of rubber has been attributed to reaction with atmospheric ozone. The susceptibility of rubbers and synthetic elastomers to attack by microorganisms has been investigated at tropic exposure sites. It was once thought that natural and synthetic rubbers were immune to microbial attack. Nevertheless, evidence seems to indicate that microorganisms can attack certain types of rubbers. The susceptibility of rubbers to microbiological growth appears to be a function of the concentrations of compounding materials within the rubbers. It was found that mixed cultures of fungi as compared with single cultures were especially deteriorative to rubber.

- **Metals**

Deterioration of metallic materials by tropic exposure is severe and occurs in many ways. Corrosion caused by chemical reactions on the metallic surface is the most common form of deterioration which occurs on metals. Almost all metals undergo deterioration by oxidative reaction within a short time of being exposed to atmospheric conditions. These reactions, however, may form a thin film of metallic oxide on the surface which ultimately renders the metal less susceptible to corrosive attack. Investigations have shown that the rate of metal corrosion increases as a result of moisture. Moisture causing corrosion results from rainfall, humidity, and condensation upon the surface of the metal. Research in the methods of corrosion control was the main objective of investigations in metals during the past quarter-century. By studying the nature of corrosion on metals as a result of exposure to environmental conditions, factors influencing the rate and intensity of attack may be investigated. Investigations have shown that protection of a metal may by accomplished by employing a protective coating, such as plating or paint, as an impermeable seal or physical barrier to prevent the corrosive medium from reaching the metallic surface. Some types of coatings, such as galvanizing and aluminizing, furnish a sacrificial anodic film and thus give cathodic protection to the coated metal. In principle, most techniques in use by the military today for protection of metallic parts are variations of these two principles.

- **Textiles**

Textile materials are extremely susceptible to environmental degradation. Actinic and biological deterioration as a result of exposure to environmental factors such as rain, sunlight, humidity and similar conditions necessitated the need for scientific investigations in this area. Textile materials for which environmental exposure tests have been investigated include clothing, netting, tentage, and sandbags. It was found that the most severe conditions affecting textile materials are actinic radiation and microbiological growth. Both conditions produce many degradative indicators, such as spotting, loss of tensile strength, flexibility and elongation changes, etc. As a result of these investigations at tropic exposure sites, many methods and treatments have been developed for the protection of textiles.

5. CONCLUSIONS

Because the overall objective of this report was to present a historical development of tropic exposure sites and associated studies of material deterioration, only conclusions of a historical nature may be drawn. As this study has indicated, much of the research in trying to solve problems inherent with exposure in a tropic environment was conducted

from the year 1945 through 1970. As a result of this research many problems encountered by military organizations in World War II and before have been studied and protective measures proposed. But the problem of deterioration of materials in the tropics is by no means solved and still presents a problem today. As evidenced by this study, world-wide standardization of nomenclature, measurement units and testing methodology remains a very real problem in assessing results of previous investigations.

Major gaps still exist in understanding results of Army materiel testing. Some of the problems which present gaps in understanding are:

- Ultraviolet and related light effects upon exposure
- Relationship of microbiological growth to materiel deterioration
- Development of a reliable method for assessing microbial damage nondestructively
- Wetting and drying cycle of moisture and its effect on degradation
- Apparent cyclic changes in tensile strength of exposed materiel, which have been observed and reported by numerous authors many times in the past quarter century. Many hypotheses have been advanced comparing these observed effects and the mechanisms of tropic exposure degradation, but none has been satisfactorily validated.

In order to qualitatively and quantitatively define the effects of tropic exposure upon materiel deterioration, then, there must be a correlation between environmental field exposure and exposure simulated in the laboratory under controlled conditions. Thus, in order to narrow the gap between an unexplained phenomenon and scientific reasoning, the major factors influencing tropic degradation must be defined and contributing influences understood.

6. RECOMMENDATIONS

No change in Test Operation Procedures is recommended as a result of this survey.

SECTION B. APPENDICES
APPENDIX I. CORRESPONDENCE

(COPY)

DEPARTMENT OF THE ARMY
HEADQUARTERS, U. S. ARMY TEST AND EVALUATION COMMAND
Aberdeen Proving Ground, Maryland 21005

AMSTE-SA 8 January 1969

SUBJECT: Storage of Test Items

Commanding Officer
U. S. Army Tropic Test Center
Drawer 942
Fort Clayton, Canal Zone

1. One of the effects sought in tests of many items of materiel is that of storage. The determination of the storage effects is sometimes accomplished by periodic removal, examination, and operation. An example of the type of materiel which will undergo this sequence is the Test Set, Chemical Agent Alarm, XM74.

2. One of the many advantages of testing materiel in the Canal Zone is the availability of a variety of tropic environments. Because of this variety and the possibility of different effects of the environments on materials, the question arises as to whether the location of the storage area provides the maximum adverse environment to all types of materials. Conversely, should there be more than one storage area to obtain a better representation of the tropic environments? This question can be illustrated by the several locations used for the test panels.

3. Concurrent with the desire to optimize the storage location(s) is the importance of having a knowledge of the materials used in the assembly of an item and particularly those materials which might be adversely affected by a given environment. Also, there are perhaps other than deterioration characteristics which would result from storage in a specific location and these should be considered together with the types of materials.

4. Your comments on this matter are requested.

FOR THE COMMANDER:

/s/Benjamin S. Goodwin
/t/BENJAMIN S. GOODWIN
Special Assistant

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DEPARTMENT OF THE ARMY
HEADQUARTERS, U. S. ARMY TEST AND EVALUATION COMMAND
Aberdeen Proving Ground, Maryland 21005

Mr. Wise/js/5221

AMSTE-TS-M

6 April 1970

SUBJECT: Test Methodology Directive, Project 1E665702D625-09

Commanding Officer
US Army Tropic Test Center
Post Office Drawer 942
ATTN: STETC-TS-OP
Fort Clayton, Canal Zone

1. Reference letter, STETC-MR-D, dated 20 Mar 70, subject: Determination of Optimum Tropical Storage and Exposure Sites—Phase I.

2. The inclosed TRMS Forms STE 1188 and 1189 constitute a test directive for the task entitled:

9-CO-009-000-004 Determination of Optimum Tropical Storage and Exposure Sites—Phase I $19,000

3. Final reports are due in accordance with provisions of TECR 70-12. Interim reports for each task will be submitted in accordance with separate instructions provided for feeder reports for Improvement in Test Instrumentation and Methodology, RCS: OSCRD-134. Such reports will be submitted for report dates (30 September and 31 March) prior to completion of each task, and for the first report date following the testing completed (Test Event 40) date.

4. The test plan within the referenced letter is satisfactory. However, paragraph 14 should include the goal, "Collection of information for development of prediction models."

FOR THE COMMANDER:

/s/Frances T. Smith
/t/FRANCES T. SMITH
Asst Admin Officer

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DEPARTMENT OF THE ARMY
HEADQUARTERS, U. S. ARMY TEST AND EVALUATION COMMAND
Aberdeen Proving Ground, Maryland 21005
Mr. Wise/mgr/234-3350-5221

AMSTE-TS-M 18 September 1970

SUBJECT: Determination of Optimum Tropical Storage and Exposure Sites—Phase I, TRMS No. 9 CO 009 000 006.

Commanding Officer
US Army Tropic Test Center
ATTN: STETC-MR
Drawer 942, Fort Clayton, Canal Zone

1. Reference USATECOM Regulation 70-12, dated 3 August 1970.

2. This letter and attached TRMS forms 1188 and 1189 (Incl 1) constitute a test directive for the subject investigation under the USATECOM Methodology Improvement Program, RDT&E 1E665702 D625. The authorized cost is $19,000.

3. Interim and final reports are due in accordance with the reference. Interim reports will be submitted for each reporting period through the first report date following completion of the investigation.

4. Special Instructions:

a. TRMS No. 9-CO-009-000-006 replaces FY 70 TRMS No. 9-CO-009-000-004, for the subject investigation. All technical and financial aspects of the investigation as approved in FY 70 remain unchanged. Any deviation from the approved scope, procedures or authorized cost will require approval from this headquarters prior to execution.

b. New MTP's or required revisions to existing MTP's which are required as a result of this investigation must be prepared and submitted to this headquarters with the final report.

FOR THE COMMANDER:

1 Incl
as

/s/George T. Morris, Jr.
/t/GEORGE T. MORRIS, JR.
Colonel, GS
Director, Test Systems Analysis

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DEPARTMENT OF THE ARMY
UNITED STATES ARMY TROPIC TEST CENTER
Fort Clayton, Canal Zone

STETC-PD-M 13 March 1972

SUBJECT: Determination of Optimum Tropical Storage and Exposure Sites—Phase I and Phase II

Commanding General
US Army Test and Evaluation Command
ATTN: AMSTE-PA-M
Aberdeen Proving Ground, Maryland 21005

1. References:

a. Letter, AMSTE-PA-M, 21 July 1971, subject: Determination of Optimum Tropical Storage and Exposure Sites—Phase I—TRMS No. 9-CO-009-000-006.

b. Letter, AMSTE-PA-M, 21 July 1971, subject: Determination of Optimum Tropical Storage and Exposure Sites—Phase II—TRMS No. 9-CO-009-000-005.

2. Referenced methodology investigations require a four month extension beyond the scheduled test completion date of June 1972 for the following reasons:

a. The investigations were proposed and approved as a two year effort. The investigations were formally initiated in September 1970.

b. Data analysis is presently behind schedule due to chemical instrumentation maintenance and repair difficulties experienced during the last 12 months. The infrared spectrophotometer, one of the basic tools, became totally inoperative and a new instrument is under procurement. As a result, a very large chemical backlog has built up. Procurement delays were also experienced in obtaining accessories for the tensile tester.

c. Our initial recruitment effort for the materials engineer and chemist vacancies was successful only after the investigation was 7 months underway. Now the chemist position is vacant due to resignation and new recruitment action is being followed. A replacement is not expected until approximately 1 May 1972.

3. Upon approval of extension to 31 October 1972, this Center will initiate the required TRMS changes.

FOR THE COMMANDER:

/s/Robert H. Murff
/t/ROBERT H. MURFF
CPT, AGC
Administrative Officer

AMSTE-ME (13 Mar 72) 1st Ind 21 Mar 1972

SUBJECT: Determination of Optimum Tropical Storage and Exposure Sites–Phase I and Phase II

Headquarters, US Army Test and Evaluation Command, Aberdeen Proving Ground, Maryland 21005 23 Mar 1972

TO: Commanding Officer, US Army Tropic Test Center, ATTN: STETC-PD-M, Drawer 942, Ft Clayton, CZ

1. Reference letter AMSTE-PA-M, 9 March 1972, subject: Preparation of FY 1973 Execution Plan–Methodology Improvement Program.

2. The recommended extension of methodology investigations, "Determination of Optimum Tropical Storage and Exposure Sites (Phase I and II)"–TRMS numbers 9-CO-009-000-005 and 9-CO-009-000-006 has been approved.

3. Extension of the investigations to 31 October 1972 will require the use of FY 73 funds starting on 1 July 1972; consequently, these investigations must be included in the response to Reference 1. In addition, any FY 72 funds associated with these investigations that cannot be obligated as a result of the delay in effort must be returned to this headquarters.

4. Request that information concerning unobligated FY 72 funds associated with the subject methodology efforts be provided to this Headquarters, ATTN: AMSTE-ME by COB 24 April 1972.

FOR THE COMMANDER:

/s/W. L. Stone, LTC
/t/GEORGE T. MORRIS, JR.
Director, Plans and Analysis

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Updated 17 April 1972

1. TITLE: Determination of Optimum Tropical Storage and Exposure Sites 9 CO 009 000 006

2. INSTALLATION: US Army Tropic Test Center
P. O. Drawer 942
Fort Clayton, Canal Zone

3. PRINCIPAL INVESTIGATOR: George W. Gauger
Analysis Division
STETC-AD
Autovon 313-2 87-3762

4. STATEMENT OF THE PROBLEM: Tropic storage deterioration testing currently being conducted at the Tropic Test Center is of doubtful validity because test items are being exposed only in a few areas in close geographical proximity. Deterioration is currently being determined by visual observations only. No measurements of the extent or rate of deterioration are being conducted. Test items frequently are limited in number and only three or four may be available. These items cannot be subjected to destructive testing because they must be returned to the testing agency, hence it is impossible to determine the cause of failure.

5. DESCRIPTION OF INVESTIGATION: a. The U.S. Army Tropic Test Center will determine optimum sites for tropical materiel tests by determining the severity of deterioration of selected materiel exposed in present exposure sites and in new exposure sites. Deterioration rate data will be collected from the materials exposed at each site. The data will be collected from the materials exposed at each site. The data obtained will then be used to classify the deterioration severity of a given site. A variety of representative materials commonly used as components of materiel end-items will be exposed. TTC will also develop nondestructive techniques for measuring material deterioration.

b. The U. S. Army Tropic Test Center (TTC) will undertake the following investigations:

(1) Survey the existing literature that pertains to deterioration of materials exposed to the tropics. Technical repositories, such as the Defense Documentation Center, Armed Service Technical Information Agency, Remote Area Conflict Information Center and specialized libraries will be asked to supply pertinent information. Military sources such as Technical Manual 743-200, "Storage of Materiel" will also be surveyed for relevant information.

(2) Select basic materials used in the construction of military items. These materials must be composed of known ingredients, so that accurate and reliable deterioration rates can be established. These materials will include paints, polymers, metals, elastomers, paper, and cloth.

(3) Determine the relative severity of effects of the different environments available for the Center's use. Many different environments, including: open, savannah, evergreen forest, semideciduous forests, and coastal sites exist in the Canal Zone, however not all of them have been "calibrated" with respect to deterioration severity.

(4) Measure auxiliary atmospheric measurements such as: microclimates, salt content, solar radiation, ozone, and microbial content at selected sites.

(5) Determine onset of deterioration as opposed to failure by measuring as many deterioration changes as possible, by the use of destructive and nondestructive test methods. The technical literature will constantly be surveyed to incorporate new techniques into the program.

(6) Determine deterioration rates and patterns. Deterioration rates and patterns can be detected with the aid of the microscope and specialized photoelectric spectrophotometers. These instruments will be utilized in this investigation.

(7) The results, if definitive, will be incorporated into a new tropic storage and exposure TOP.

6. REASONS FOR CONDUCTING INVESTIGATION: a. Present Capability.

(1) Microbiological inspections and services were conducted on 63 tests during the past three years. The information gathered, however, has not allowed the development of cause and effect relationships because the number of test items were limited and could not be destroyed in testing. It is therefore oftentimes impossible to determine the rates, patterns, and reasons for failure of the test items.

(2) The effects of tropic environmental storage are presently determined by the detection of gross changes in materiel (rips, cracks, fading, softening, etc.).

(3) Over 80% of tropic storage testing is conducted at two sites representing only two environmental types.

(4) Many of the storage and exposure sites now available for TTC use were selected for practical reasons with little consideration for significant environmental conditions.

b. Limitations of Present Capability.

(1) A greater number of material samples must be exposed so that cause and effect relationships can be established.

(2) Methods of detecting non-visual deterioration changes on materiel end-items must be developed.

(3) Deterioration rates and patterns must be determined for all major vegetation terrain types available to TTC to assure adequate testing under representatively severe conditions.

(4) A greater number of test sites must be used. Several natural environmental types exist in the Canal Zone, however, the deterioration severity of the sites and their suitability for testing certain kinds of materials has not been ascertained.

c. Anticipated Improvements to Result from Investigation

TITLE: Determination of Optimum Tropical Storage and Exposure Sites 9 CO 009 000 006

(1) Establish cause and effect relationships between environment and materiel.

(2) Detect early manifestations of deterioration.

(3) Establish deterioration rates and patterns.

(4) Determine optimum uses of each TTC storage and exposure site by calibrating sites with respect to known severity.

d. Pertinence to TECOM Mission.

TECOM bears major responsibility for the tropic tests of Army materiel items, thus investigations that will define optimum test sites for equipment will benefit TECOM operations more than any other organization. The present investigation will use non-test data to benefit test methodology.

AMC sponsored deterioration projects (Frankford Arsenal, USAECOM, USAMERDC) in the Canal Zone do not address the same objectives as the present project. The AMC projects are long-term (5—25 years) and are done mostly in coastal sites. The AMC projects are designed to follow the materials through to complete destruction or failure. This Center has supported the AMC tests for eight years and has received no feed back to assist the test effort. The present project is designed to yield a higher data rate and to use more sophisticated laboratory analyses than the AMC projects.

7. IMPACT IF NOT FUNDED OR DELAYED. a. Impact statements for the following two conditions:

(1) The investigation will not be conducted.

(a) Effects of failure to fund:

(i) TTC storage and exposure sites cannot be calibrated for environmental severity.

(ii) Nondestructive test methods will not be developed.

(iii) The tropical storage and exposure TOP will not be written.

(iv) Methods for shortening tropic storage tests will not be developed.

(v) Failure expectancies representative of components used in end item of materiel will not be established.

(b) List of requirements taken from specified requirements documents (QMR, SDR) which will not be met due to inability either to adequately test or analyze the resulting test data.

(i) Small Development Requirement for Remote Area Lightweight Multi-Weapons Armorer's Repair Kit. "Be resistant to fungi, insects, mildew, corrosion, moisture and vapor."

(ii) "Be capable of safe storage (5 years) and transportation by individuals participating in missions within an Unconventional Warfare Operational Area under hot-dry, warm-wet, intermediate, and cold climate conditions, as defined in paragraph 7, C1, AR 705-15."

(iii) "Small Development Requirement for Army Aircraft Weapons Handling Vehicle, Multipurpose." "Materials will be such as to provide maximum resistance to rust, corrosion and deterioration in service and prolonged storage." "Construction materials used will provide maximum resistance to harmful effects on rodents, fungi, humidity, rain, snow, salt water, and wind and will have a useful life span of at least 10 years."

(iv) Small Development Requirement for a Lightweight Camouflage Screening System. "Be resistant to mold, rot, fungus, corrosion, and color fading."

(v) Small Development Requirement for Cold Water Detergent. "Detergent shall remain stable in storage under conditions defined in AR 705-15, para 7a, b, c, and d."

(vi) Small Development Requirement for Epidemiological Survey Kit. "The end times contained within the inserts must be resistant to moisture and fungus type deteriorations encountered in hot-wet environment. Exterior carrying case and internal inserts must withstand the moisture hazard encountered on fording small rivers and streams, to the same degree as the Portable Medical Laboratory referred to in paragraph 2b(2)(g)."

(vii) Small Development Requirement for Lightweight Recompression Chamber. "Use construction materials that will provide maximum resistance to harmful effects of rodents, insects, fungi, humidity, rain, snow, ice, salt water, and wind."

(viii) Small Development Requirement for a Multicircuit firing Device. "Have a 95% probability of functioning as described in 2c(11) above in wet-warm, wet-hot, humid-hot coastal desert, hot dry, intermediate hot-dry, intermediate cold and cold climate categories after field storage for at least 3 months prior to use and transportation in using unit vehicles or trailers for 3000 miles - - -"

(ix) Small Development Requirement for Lightweight, Expendable Pallet, Airmobile. "The expandable pallet shall be resistant to all usual weather conditions encountered in Army supply and storage operations in the field." "Preclude softening beyond use under tropic conditions." "Withstand rain (water) that may be expected under monsoon conditions common to S.E. Asia."

(x) Small Development Requirement for a Portable Sign Making Kit. "Be capable of being employed and functioning properly and/or stored under field conditions in hot dry, warm wet, intermediate and cold climatic conditions as defined in para 7, C1, AR 705-15."

(xi) Small Development Requirement for Remote Area Demolitionist's Equipment Kit. "Be capable of being employed and functioning properly and/or under field conditions in wet-warm, wet-dry, humid-hot coastal desert, hot-dry, intermediate hot dry, intermediate cold and cold climatic categories defined in Chapter 2, AR 70-38." "Except for active explosions and impairment of capabilities from effects of extreme conditions for 2 years in warm-wet, wet-dry, humid-hot coastal desert, hot-dry, intermediate hot dry, intermediate cold and cold climatic categories defined in Chapter 2, AR 70-38."

TITLE: Determination of Optimum Tropical Storage and Exposure Sites 9 CO 009 000 006

(xii) Small Development Requirement for a Water Quality Analysis Set. "Set shall be capable of operation, safe storage and transportation without permanent impairment of its capabilities from the effect of climatic categories 1, 2, 3, 4, 5, and 6 as delineated in AR 70-38."

(2) The investigation will be deferred until the FY 74.

(a) Effects of delay in funding.

(i) Delay maximum effective use of the natural environments available.

(ii) Delay the optimum use of TTC's storage and exposure sites.

(iii) Delay development of methods for shortening and improving tests.

(iv) Delay the establishment of a tropical storage and exposure MTP.

(v) Delay the establishment of failure expectancies representative of components used in end item of materiel.

(vi) Delay development of nondestructive tropic tests of materiel.

(vii) Scientific and engineering man-hours and $30,414 spent to date would be wasted.

(b) Same as paragraph 7(1)b.

(3) Man-hours and dollars spent to date: Man-hours–4,544 Dollars–$30,414.

8. TEST PROJECTS TO BENEFIT FROM THE INVESTIGATION:

TITLE	TRMS NO.		FY			
			74	75	76	77
Missile, 152mm Heat MGM 51	1MI	014 051 002	SU	SU	SU	SU
Missile, Shillelagh, Spt Storage Test	1MI	014 051 008	ST	ST	ST	ST
Rocket Motor M66 Tropic Storage	2MI	111 066 001				
Propellants, Prediction, Safe Life	2MU	005 000 001	PI			
Surveillance Program for S&A Device M30A1 (Nike Hercules)	3MI	080 030 002	SU	SU	SU	SU
Mask, Aircraft, Protective M24	5EI	820 024 005	SU	SU	SU	SU
Mask, Protective, Tank, M25A1	5EI	820 025 001	SU	SU	SU	
Detector Unit, Chemical Agent, Alarm XM8	5ES	300 008 004	SU	SU	SU	SU
Kit, Sampling & Analysis, CBR, M-19E34	5ES	630 019 003	SU	SU	SU	SU
Kit, Chemical Agent, Detector, M18A2	5ES	680 018 004	SU	SU	SU	SU
Burster, Field, Incendiary M4	5MU	018 004 005	SU	SU	SU	
Launcher, Tactical, CS, 16 Tube	5WE	F00 008 001	SU	SU	SU	
TOW 15 yr Surveillance Program	8MI	000 TOW013	SU	SU	SU	SU

TITLE: Determination of Optimum Tropical Storage and Exposure Sites 9 CO 009 000 006

9. RESOURCES: a. Financial

	Dollars in Thousands FY 73 In-house	Out-of-house
Personnel Compensation		
Permanent Full-time	7.8	—
Part Time		
Travel	—	—
Contractual Support	—	—
Consultants & Other Svcs	—	—
Materials & Supplies	2.0	—
Equipment	—	—
G&A Costs	15.1	—
Subtotals	24.9	0
FY Total	24.9	

b. Explanation of Cost Categories.

(1) N/A

(2) N/A

(3) Contractual support will be required to assist in data collection, storage and reduction.

(4) N/A

(5) N/A

(6) N/A

(7) G&A Costs are computed at the rate of $15.50 per direct labor man-hours. This rate, provided by TTC Budget Office, includes overhead cost and host-tenant agreement support cost.

c. Obligation Plan.

	FY 73				
FQ	1	2	3	4	TOTAL
	18.6	6.3			24.9

d. In-House Personnel.

	Number	Man-hours, FY 73 Required	Available	Total Man-hours Required
Microbiologist, GS 0403	1	200	200	400
Materials Engineer, GS 0806	1	200	200	400
Chem Engr Asst (01G20)	1	320	320	640
Chemist, GS 1320	1	200	0	200
Engineer Tech, GS 0802	1	20	20	40
Meteorologist, GS 01340	1	35	35	70
		975	775	1750

TITLE: Determination of Optimum Tropical Storage and Exposure Sites 9 CO 009 000 006

(2) Resolution of nonavailable personnel. Chemist position is a TDA slot presently vacant but candidate has been selected and is expected to be available on or about 1 May 1972.

10. INVESTIGATION SCHEDULE:

	FY 72
	J A S O N D
In-house	– – – – – R
Contract	– – – –

Consultants: Not applicable.

11. ASSOCIATION WITH IMP: N/A

12. ASSOCIATION WITH MTP/TOP PROGRAM: A new Test Operations Procedure will be written titled, "Tropic Exposure Considerations."

/s/Hyrum Dallinga
/t/HYRUM DALLINGA
COL, Inf
Commanding

(END COPY)

(COPY)
DEPARTMENT OF THE ARMY
HEADQUARTERS, U. S. ARMY TEST AND EVALUATION COMMAND
Aberdeen Proving Ground, Maryland 21005

Mr. Champion/dg/870-5332

AMSTE-ME 21 July 1972

SUBJECT: Determination of Optimum Tropical Storage and Exposure Sites--Phase I, TRMS No. 9-CO-009-000-006

Commanding Officer
USA Tropic Test Center
ATTN: STETC-PD-M
Drawer 942
Ft. Clayton, CZ

1. Reference TECOM Regulation 70-12 dated 3 August 1970.

2. This letter constitutes a test directive for continuing the subject investigation under the TECOM Methodology Improvement Program, RDT&E 1U665702D625.

3. Subject investigation is recognized by this headquarters as a multi-year effort. The authorized cost for FY 73 is $24,900.

4. Special Instructions.

a. The methodology investigation proposal (Incl 1) is the basis for headquarters technical and financial approval of the subject investigation. Any deviation from the approved scope, procedures or authorized cost will require approval from this headquarters prior to execution.

b. An interim report will be submitted to this headquarters, ATTN: AMSTE-ME, on 15 November 1972 and the final report is due 15 January 1973.

c. Required changes in TRMS will be made by TTC.

d. Recommendations on new TOPs or revisions to existing TOPs will be included as part of the Recommendation Section of the final report. New or revised TOPs will not be required to be submitted with the final report. Final decision on the scope of the TOP effort will be made by this headquarters as part of the report approval process.

5. In case of conflict, guidance provided in this letter will take precedence over that shown in reference 1a.

FOR THE COMMANDER:

/s/Sidney Wise
/t/SIDNEY WISE
Methodology Improvement Dir

1 Incl
as

(END COPY)

APPENDIX II. REFERENCES

1. Abrams, E. *Apparent Mildew Resistance of Weathered Cotton Duck,* Textile Research J. 21: 714-720, October 1951.

2. Ambler, H. R., and Bain, A. A. *Corrosion of Metals in the Tropics,* J. Applied Chemistry, 5 September 1955.

3. Babakov, A. A., and Tufanov, D. G. *Corrosion of Steels Under Atmospheric Conditions* (in Russian), Zhur. Priklad. Khim 33: 1334-1340, 1960.

4. Bakanauskas, S. *Outdoor Weathering Evaluation of Synthetic Fiber Materials,* Wright Air Development Center, Technical Note WCRT 53-234, December 1953.

5. Barghoorn, E. S., Jr. *Field Studies of the Deterioration of Textiles under Tropical Conditions,* U. S. Quartermaster Corps, Military Planning Division. Textile Series Report No. 24, Microbiological Series Report No. 4.

6. Baskin, D. A., and Kaplan, Arthur. *An Approach to the Kinetics of Microbial Deterioration,* Applied Microbiology, Vol. 8. No. 5, September 1960.

7. Beckman, E. Mck. *The Climatic Deterioration of Plastics and Plasticizers,* United States Joint Army-Navy Deterioration Prevention Committee, Minutes of the Seventh Meeting, April 1947.

8. Bennicelli, C. *Report of Investigation of Fungus Resistance of some Raw and Compounded Vulcanized Natural and Synthetic Elastomers,* US Naval Shipyard, Brooklyn, N. Y., Material Lab Project 5129-4, Report 1, January 1957.

9. Bersch, C. F., Harvey, M. R., and Achhammer, G. G. *Heat and Ultraviolet Aging of Poly(Vinyl Chloride),* J. Research, Matl. Bur. Standards, 60:481-488, May 1958.

10. Bjorksten, J., and Lappala, R. P. *Photodegradation of Plastic Films,* Plastics Technology 3:25-27, January 1957.

11. Blahnik, R., and Zanova, V. *Microbiological Corrosion,* Czechoslovakia, FTD-TT-65-1641, AD 803 784.

12. Blake, J. T., Kitchin, D. W., and Pratt, S. O. *The Microbiological Deterioration of Rubber Insulation,* AIEE, New York, Technical Paper 53-59, December 1952.

13. Bloch, A. N. *Materiel Deterioration: Its Causes and Control,* United States Army Chemical Corps, Army Chemical Center, Md. ENCS-DE-S-5, September 1959.

14. Boneh, Shira. *Contribution to the Knowledge of Some Textile-Destroying Fungi in Israel,* Palestine Journal of Botany, Jerusalem Series 6: 107-115, October 1953.

15. Brown, A. E. *Problem of Fungal Growth on Synthetic Resins, Plastics and Plasticizers.* OSRD Report No. 6067, TDAC, USNDRC, October 1945.

16. Bush, Vannevar, *et al. Tropical Deterioration of Equipment and Materials,* PB 81801. W1065125, Vol 1, 1946.

17. Byalobezhskii, A. B. *The Effect of Ionizing Radiation on the Corrosion of Metals under Atmospheric Conditions* (in Russian with English summary) Ahur. Fiz. Khim. 33: 1256-1262, June 1959.

18. Chu, C. C., Kenney, R. A., Kaswell, E. R., and Stavrakas, E. J. *The Measurement of Ultraviolet Reflectance as a Criterion of Nylon Fabric Deterioration,* Fabric Research Labs Inc., AD273105 ASD Tech. Report 61-560, WPAFB, Ohio, November 1961.

19. Connell, V. *Brief Description of New West African Tropical Testing Establishment, Port Harcourt, Nigeria,* Letter to W. C. Ellis, February 1947.

20. Controller General of Inspection, India. *A Preliminary List of Microorganisms which Cause Damage to Ordnance Stores in India,* C. G. I Technical Report No. Bio/45/5, March 1945.

21. Copson, H. R. *A Theory on the Mechanism of Rusting of Low Alloy Steels in the Atmosphere,* ASTM Proceedings, 45: 554-590, 1945.

22. Dean, J. D., and Warner, R. K. *The Degradation of Untreated Cotton Fabrics Exposed to Weather in a Subtropical Climate,* Am. Dyestuff Reptr. 36 (15): 405-410, 423-424, July 1947.

23. Dearden J. *Climatic Effects on the Corrosion of Steel,* J. Iron Steel Institute 159: 241-246, July 1948.

24. DeCoste, J. B., Howard, J. B., and Wallder, V. T. *Weathering of Poly (Vinyl Chloride). Effect of Composition,* Chemical and Engineer Data Series 3:131-140, April 1958.

25. DeCoste, J. B., and Wallder, V. T. *Weathering of Polyvinylchloride,* Ind. Eng Chem. 47: 314-322, February 1955.

26. Delfosse, Pierre. *Effect of Plasticizer Content on Thermal Aging of PVC Compounds* (in French), Ind. Plastiques Mod. (Paris) 11:57-60, 6366, September–October 1959.

27. Dickie, A. M. *Report on United States Inter-Service Fungus- and Moisture-Proofing Mission (to British Research Establishments),* October 1945.

28. Dolezel, B. *Degradation of Plastics and Rubber,* Makromolekularni Latky, U. 8, 134-143 FSTC-HT-23-694-70 (Czechoslovakia).

29. Dunkel, W. L., and Phelan, R. R. *Accelerated Ozone Aging,* Rubber Age, (N. Y.) 83: 281-286, May 1958.

30. Dychko, A. H., and Dychko, K. A. *Atmospheric Corrosion of Metals at Low Temperatures* (in Russian), Zhur. Priklad Khim. 30: 255-263, February 1957.

31. *Proceedings of Eighteenth Conference on Prevention of Microbiological Deterioration of Military Materiel,* U. S. Army Natick Laboratories Technical Report 70-61 PR, November 1969.

32. Eisenstecken, F., and Stinnes, W. *Influence of Some Elements on the Corrosion of Unalloyed Steel in Various Attacking Media* (in German), Arch. Eisenhüttenw. 27: 469-474, July 1956.

33. Electrical Equipment Panel, *Susceptibility of PVC Materials to Biological Damage,* Conference on Tropic Proofing, Gr. Brit. Ministry of Supply, July 1945.

34. Evans, U. R. *Scientific Basis of Corrosion,* Society of Instrument Technology Transactions, 7: 123-135, September 1955.

35. Feltman, Samuel, and Barrett, Robert B. *Resistance of Plastics to Outdoor Exposure,* Ordnance Project TB4–721A, Technical Report 2102, February 1955.

36. *Proceedings of Fifteenth Conference on Prevention of Microbiological Deterioration of Military Materiel,* U. S. Army Natick Laboratories Technical Report 67–80 PR, November 1966.

37. *Proceeding of Fourteenth Conference on Prevention of Microbiological Deterioration of Military Materiel,* U. S. Army Natick Laboratories Technical Report 66–47 PR, November 1965.

38. Frant, M. S. *Comparison of Corrosion Rates in Different Test Locations,* Plating 45: 734–738, July 1958.

39. Great Britain Ministry of Aviation, *Reports on Plastics in the Tropics, 12. Polyvinyl Chloride,* 1960.

40. Great Britain Ministry of Supply, Technical Information and Library Services, *Reports on Plastics in the Tropics, 5. Nylon Monofilaments,* TIL (BR) 303: AST1A Doc. 149777, 1957.

41. Greathouse, G. A. *Effect of Microorganisms on Rubber Degradation,* Rubber Age, 63: 337–338.

42. Grossman, R. F., and Bluestein, A. C. *Ozone Resistance of Butyl Rubbers,* Rubber Age (N. Y.) 84:440–443, December 1958.

43. Grumbles, M. A., Jr., and Moore, K. K. *The Study of Effect of Atmospheric Environment on Corrosion Rates of Steel,* Am. Paint. J. 43(48): 68–84, 1959.

44. Guttman, H., and Sereda, P. J. *Measurement of Atmospheric Factors Affecting the Corrosion of Metals.* ASTM Paper No. 18, June 1968.

45. Hache, A. *Study of Stress Corrosion of Some Mild Steels Exposed to Natural Environments* (in French), Rev-Met. 55: 656–678, July 1958.

46. Hanson, A. C. *Tropical Storage of Rubber and Neoprene,* U. S. Arsenal Rock Island, Illinois. Report No. 40-2983, June 1940.

47. Hargreaves, F. *A Note on Filiform Corrosion,* J. Iron Steel Institute 171: 47–48, May 1952.

48. Hargreaves, F. *Incipient Corrosion of Steel; Study of Its Initiation and Progress,* Metal Treatment 19: 385–390, September 1952.

49. Hashimoto, T. *The Photochemical Degradation of 6 Nylon,* Bull. Chem. Soc. Japan, 30: 950–952, December 1957.

50. Heinisch, K. F., and Kuhr, P. *The Growth of Fungi on Rubber,* Arch. Rubber Cultivation (Bogor) 34: 1–17, April 1957.

51. Hessler, L. E. and Upton, D. J. *Chemical Properties of Field-Weathered Cotton.* J. Textile Research, 25: 1029-1034, December 1955.

52. Holzwarth, J. C., Thomson, R. F., and Boegehold, A. L. *A Study of Non Protective Rust Formation on Auto-Body Sheet Steel,* S.A.E. Trans., 64:221–228, 1956.

53. Hudson, J. C. *The Atmospheric Corrosion of Iron and Steel Wires.* BISRA, London, Paper MG/BB/12/48, J. Iron Steel Institute (London) 160: 276–285, November 1948.

54. Hudson, J. C. *The Corrosion of Iron and Steel,* J. Sci. Instruments, 22: 231–235, 1945.

55. Hudson, J. C., and Stanners, J. F. *The Corrosion Resistance of Low Alloy Steels,* J. Iron & Steel Institute V. 180, July 1955.

56. Hudson, J. C., and Stanners, J. F. *The Protection of Iron and Steel by Metallic and Nonmetallic Coatings.,* J. Iron & Steel Institute, V. 175, December 1953.

57. Hudson, J. C. and Stanners, J. F. *The Effect of Climate and Air Pollution on Corrosion.* J. Applied Chem (London) 3: 86–96, February 1953.

58. Hueck, H. J. *The Biological Deterioration of Plastics* (in Dutch with English summary), Plastica 12: 24–35, January 1959.

59. Hutchinson, W. G. *Development of a Method for Testing the Resistance of Plastics to Fungus Attack,* OSRD Report No. 5688, October 1945.

60. Hutchinson, W. G. *The Deterioration of Materiel in the Tropics,* Sci. Monthly 63: 165–177, 1946.

61. Imoto, T., and Ogo, Y. *Photodecomposition of Polyvinylchloride Fiber* (in Japanese, with English Summary), J. Japan Soc. Text 6 Cellulose Ind. 12: 823–827.

62. Indian Standards Institution, New Delhi. *Method for Detection and Estimation of Damage in Cotton Fabrics Due to Microorganisms,* Indian Standard IS: 1316–1958, September 1959.

63. Iofa, Z. A., and Besproskurnov, G. G. *A Study of the Mechanisms of Atmospheric Corrosion of Iron in the Presence of Sulfur Dioxide as Aggressive Agent* (in Russian with English summary), Zhur. Fiz. Khim. 31: 2236–2244, October 1957.

64. Iwamoto, Kikuchi and Ooyama. *Studies on Mold Growth Prevention in Industrial Products. 18. On Microbial Deterioration of Natural Rubbers and Synthetic Rubbers,* January 1967 (Japan).

65. *Joint Army-Navy Deterioration Prevention Committee–Main Committee Minutes of the First Meeting,* February 1946.

66. Kadyrov, S. *Effect of Sunlight on the Properties of Cotton,* Tekstil. Prom. 16(9): 14–16, 1956.

67. Kaiser, Rudolf. *Crack Growth and Crack Testing in Natural Rubber and Synthetic Elastomers* (in German), Kautschuk u. Gumm: 8:WT145–WT152, June 1955.

68. Korshak, V. V., Slonimskii, G. L., and Krongauz, E. S. *Thermal Destruction of Hexamethylene Adipamide* (in Russian), Otdel. Khim. Nauk No. 2: 221–226, 1958.

69. Klemme, D. E., Greathouse, G. A., Bullenbacher, K., and Pope, S. *The Deterioration of Cotton Fabrics by Certain Microorganisms,* Circular 737, USDA, September 1945.

70. LaQue, F. L. *Corrosion of Automobile Bodies,* SAE Journal 61(7): 78–80, July 1953.

71. Larrabee, C. P. *Corrosion Resistance of High-Strength, Low Alloy Steels as Influenced by Composition and Environment,* Corrosion 9: 259–271, August 1953.

72. Leonard, J. M. *NRL Tropical Exposure Facilities,* NRL Report No. C-3073, April 1947.

73. Lonsdale, J. E. *Report on a Visit to the West African Tropical Testing Establishment,* Lagos, Nigeria, Great Britain Ministry of Supply, Controller of Research and Development, May 1945.

74. Mikhailovskii, Yu. N., and Tomashov, N. D. *Method for the Electrochemical Investigation of Atmospheric Corrosion at Relative Humidities of 100 Percent and Less* (in Russian), Zavodskaya Laboratory 23: 1462–1466, December 1957.

75. Morris, M. A., and Wilsey, B. *The Effect of Soil on the Photochemical Degradation of Cotton,* Textile Research J. 29: 971–974, December 1959.

76. Nette, I. T., Pomortseva, N. V., and Kozlova, E. I. *Destruction of Rubber by Microorganisms,* Microbiology 28: 821–827, November–December 1959.

77. Neu, R. F. *Ozone Resistance and Weatherability of Butyl Compounds,* Report ELD 6815, April 1957.

78. Nopitsch, M., and Mobus, E. *Does Aspergillus Niger Possess Cellulose Destroying Power?* (in German with English summary), Melliand Textilber. 40: 677–680, June 1959.

79. Norkraus, B., and Ranby, B. G. *Studies of the Enzymatic Degradation of Cellulose,* Physiol. Plantarum 9: 198–211, 1956.

80. Office of Scientific Research and Development. TDAC, *Handbook of Some Fungi Associated with Tropical Deterioration,* OSRD Report 6267, October 1945.

81. Office of Scientific Research and Development. *The Tropical Test Station at Barro Colorado Island,* OSRD Report 567D, 31 October 1945.

82. Ogburn, F., Weaver, E. R., and Blum, W. *Influence of Relative Humidity and of Surface Conditions on the Corrosion of Low Carbon Steel and Zinc,* Metaux and Corrosion, 24: 77–84, 1949.

83. Passono, A. J. *Technical Aspects of Tropicalization and Protective Coatings as Applied by the Japanese to Military Equipment,* U.S.O.T.S. Publication Board No. PB-27690, December 1945.

84. Postouskaya, A. F., and Kuzminskii, A. S. *The Kinetics of the Oxidation of Rubber under the Influence of Light,* Doklady Akad. Nauk SSSR, 90: 209–212, 1953.

85. Preston, R. St. J. and Sanyal, B. *Atmospheric Corrosion by Nuclei,* J. Applied Chemistry, 6: 26–44, January 1956.

86. *Proceedings of the Thirteenth Conference on Prevention of Microbiological Deterioration of Military Materiel,* US Army Natick Laboratories November 1964.

87. Quackenbos, H. M., Jr. *Plasticizers in Vinyl Chloride Resins; Migration of Plasticizer.* Ind. Eng. Chem. 46: 1335–1344, June 1954.

88. Race, E. *The Degradation of Cotton during Atmospheric Exposure, Particularly in Industrial Regions,* J. Soc. Dyers Colourists 65: 56–63, February 1949.

89. Raes, G., Nicolaus, A., and Fransen, T. *Evaluation of the Degree of Microbiological Attack on Cotton and Measurement of the Intensity of Degradation* (in French with English summary), Ann. Sci. Textiles Belges No. 4: 32–52, December 1959.

90. Rajagopalan, K. S., Sundaram, M., and Annamalai, P. L. *Corrosion of Metals at Mandapam Camp, Indiu,* Corrosion15: 25–28, December 1959.

91. Rauschert, M. *Results of Tropical Resistance Tests of Plastics in the Amazon Region* (in German), Kunststoffe 45: 407–408, September 1955.

92. Rook, J. J. *Microbiological Deterioration of Vulcanized Rubber,* Applied Microbiology 3: 302–309, September 1955.

93. Royal Aircraft Establishment, Farnborough, England. *Note on Development of a Test for the Quantitative Assessment of Microbiological Deterioration of Cotton.* Chemistry Note No. 770, September 1945.

94. Rust-Oleum Corp. *Corrosion Map of the United States,* Chem. Eng. Progress, 54: 142, September 1958.

95. Sadov, F. I., and Vylcheva, R. I. *Action of Light on the Cellulose of Cotton. II. Chemical Transformation of the Cotton Cellulose Macromolecule under the Influence of Light and Atmospheric Conditions* (in Russian), Izvest. Visshikh. Ucheb. Zavedenii, Tekhnol. Tekstil. Prom. No. 1: 132–136, 1959.

96. Sandoval, R. M. *Microbial Colonization of Neoprene and Teflon*, New Mexico State University, February 1965 (Master's Thesis).

97. Sanyal, B., Nandi, A. N., Natarajan, A., and Bladwar, D. *Atmospheric Corrosion of Metals; Part 2, Corrosion of Metals in Bombay*. J. Sci. Ind. Research (India) 18A: 127–131, March 1959.

98. Sanyal, B., and Singhania, G. K. *Atmospheric Corrosion of Metals, I.* J. Sci. Ind. Research (India) 15B: 448–455, August 1956.

99. Schikorr, G. *The Inverse Dependence of the Corrosion of Metals on Some Influencing Factors* (in German), Metall 6: 350–360, 1952.

100. Schikorr, G. *On the Diagnosis of Corrosion Processes from Corrosion Products* (in German with English summary), Werkstoffe u. Korrosion 9: 552–556, August –September 1958.

101. Scientific Liaison Bureau, Brit. Empire. *Science and Tropical Warfare*, Aust. J. Sci. 8: 65–68, 1945.

102. *Proceedings of Seventeenth Conference of Prevention of Microbiological Deterioration of Military Materiel*, US Army Natick Laboratories Technical Report 69–85 PR, November 1968.

103. Shraposhnikov, V. N. *et al. The Growth of Bacteria on Natural Rubber* (in Russian), Microbiology (U.S.S.R.) 20: 146–154, March–April 1952.

104. Simpson, M. E., and Marsh, P. B. *The Decomposition of Cellulose in Cotton Fiber by the Black Aspergilli*, Plant Disease Reporter 43: 1042–1047, September 1959.

105. Siu, R. G. H., and White, W. L. *The Microbiological Degradation of Cotton Fabrics*, Microbiological Series Report No. 1, Textile Series, Report No. 6 Tropical Deterioration Research Laboratory, Philadelphia Quartermaster Depot, December 1945.

106. *Proceedings of Sixteenth Conference on Prevention of Microbiological Deterioration of Military Materiel*, US Army Natick Laboratories Technical Report 68–69 PR, November 1967.

107. Smith, W. W. (South Florida Test Service Inc.). *Natural Weathering and Indoor Open Shelf Storage Exposure Testing of Air Force Fabric Materials*, Wright Air Development Center–Technical Report 58–502 ASTIA Doc. 40226, March 1959.

108. Southwell, C. R., Forgeson, B. W., and Alexander, A. L. *Corrosion of Metals in Tropical Environments; Part 2, Atmospheric Corrosion of Ten Structural Steels*, NRL Report 5002, December 11, 1957.

109. Tamblyn, J. W., Newland, G. C., and Watson, M. I. *Early Detection of Weathering Damage in Polyethylene* Plastics Technol. 4:427–432, 455, May 1958.

110. Technical Development Establishment, Laboratory (Stores) Kanpur India. *Exposure Trial in Nylon Cordage,* Technical Report Bio/49/72, June 1949.

111. Teitell, L. *Studies of the Effects of Tropical Environments in Materials I. Description of Exposure Sites,* Frankford Arsenal Report R-1888, May 1968.

112. Teitell, L. *Weather at the Panama Canal Zone Tropical Testing Station,* Project 4–63, Report R-742, October 1946.

113. Tomashov, N. D., and Lokotilov, A. A. *Determination of the Thickness of Moisture Film on Metals Exposed to Atmospheric Corrosion* (in Russian), Zavodskaya Lab. 24: 425–427, April 1958.

114. Turner, J. N., and Kennedy, M. E. *Microflora of Crepe Rubber,* Nature 173: 506, March 1954.

115. US Army Air Forces Tropical Science Mission, *Tropical Deterioration of Air Force Material and Equipment,* May 1946.

116. US Army Test and Evaluation Command, *Testing for Fungus Resistance,* TECP 700-700, Interim Pamphlet 70–81, 30 November 1964.

117. Voight, J. *The Photochemical Degradation of Unsaturated Polyester Resins. Investigation of the UV Absorption Spectra* (in German with English summary), Makromol. Chemia 27 (½): 80–100, 1958.

118. Wellman, R. H., and McCallan, S. E. A. *Fungus Resistance of Plastics, Part I, Plastics, Components and Fungicides, Part II. Biological Factors.* OSRD Report No. 5683. TDAC-NDRL, September 1945.

119. Wessel, C. J. *Biodeterioration of Plastics,* SPE transactions, July 1964.

120. Wilson, H. S., Buchert, S. R., and Tandberg, L. F. *Report on Trip to Actinic Test Site at Las Cruces, New Mexico,* US Army Air Forces Materiel Command, Climatic Projects Section, Wright Field, Dayton, Ohio April 1947.

121. Wroblewska, D. *Influence of the Direct Action of a Tropical Environment on Polyethylene Film,* Corrosion Traitements Protection Finition.

122. Yelland, W. E. C. *Degradation from Weathering of Tentage Fabrics,* US Army Quartermaster Corps. Textile Series Report 40, September 1951.

123. Yocum, J. E. *The Deterioration of Materials in Polluted Atmospheres.,* J. Air Pollution Control Assoc. 8:203–208, November 1958.

124. Yustein, S. E. *Photomicrographic Studies of Weather Aged Plastic Materials (Transparent Plastics),* US Naval Shipyard, Brooklyn, Laboratory Project 4860-G-3, Progress Report 3, November 1958.

125. Yustein, S. E., Winans, R. R., and Stark, H. J. *Outdoor Weather Aging of Plastics under Various Climatological Conditions,* ASTM, (1950 Preprint 114) 1950.

126. Yustein, S. E., and Winans, R. R. *Report of Investigation of Outdoor Weather Aging of Plastics under Various Climatological Conditions,* US Naval Shipyard, Brooklyn, N. Y., Lab Project. 4860-G-2, Final Report, September 1952.

127. Zuck, R. K., and Diehl, W. W. *On Fungal Damage to Sun-Exposed Cotton Duck,* Am. J. Botany 33: 374–382, 1946.

APPENDIX III. ABBREVIATIONS

ACV	-	Alkali Centrifuge Value
JTRU	-	Joint Tropical Research Unit
mpy	-	mils-per-year
mu	-	millimicrons
NDRC	-	National Defense Research Committee
nm	-	nanometers
PVC	-	Polyvinylchloride
TDAC	-	Tropical Deterioration Administrative Committee
TDSC	-	Tropical Deterioration Steering Committee
UV	-	Ultraviolet
WATTE	-	West African Tropical Testing Establishment (British)